ILLUMINATING ENGINEERING

APRIL 1956

◆

Comfort and Cost in Production Lighting
Color Rendition with F-Sources
Utilization Data for Luminous Ceilings
and Lighting Applications

THE JOURNAL OF THE ILLUMINATING ENGINEERING SOCIETY

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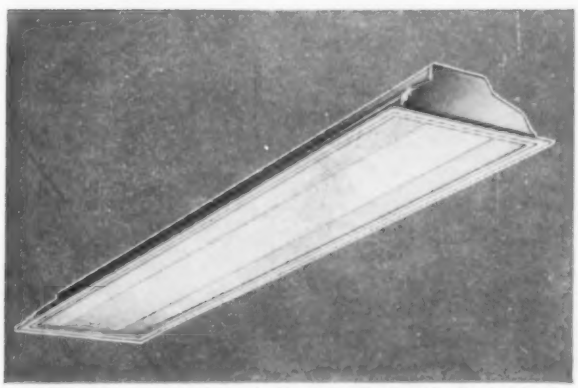

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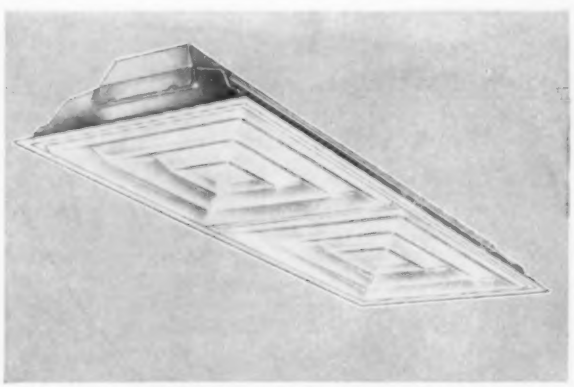

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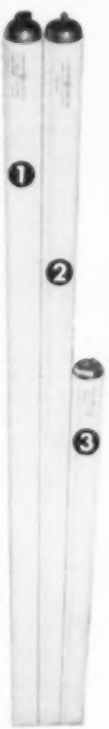

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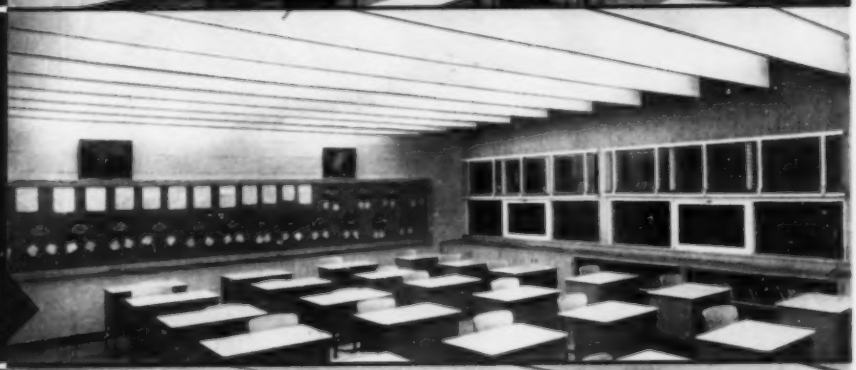

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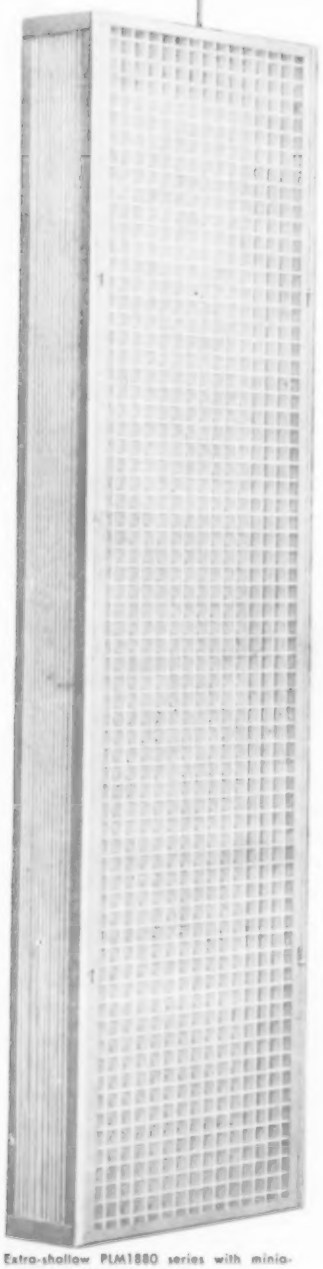

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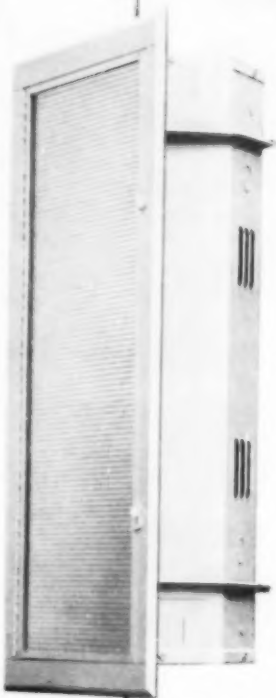

Recessed 5600 series showing improved rigidizing members

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Figure 1. The importance of higher levels of illumination and adequate uplighting for seeing comfort is readily appreciated by comparing the illumination effect in the foreground with that in the background.

Visual Comfort and Cost Analyses for

Production Lighting

By GEORGE J. TAYLOR
R. D. BRADLEY

The importance of quality lighting in industry is not only appreciated but being applied on a wide scale basis today. Luminaires, with adequate uplighting, white ceilings, attractive color schemes and light interior finishes, all combine to give high visual comfort. This paper continues a study, started by the authors in 1952, on cost and comfort evaluation of industrial lighting systems.

EXPANSION in industrial capital expenditure during the last decade in the United States has been phenomenal. Even without quotation of the statistics, this all may concede. Postwar manufacturing growth in production of materials for defense and for consumer use exceeds our most optimistic predictions.

While lighting has always been a part of plant expansion it is more and more being accepted by industrialists as a specific "tool" of industry. As such, it plays an active role in manufacturing growth in terms of increased productivity, better products and improved employee morale. Today there is a keener understanding between industrialists and lighting engineers in the true meaning of quality of illumination and its significance in relation to the one really important factor — comfort of seeing.

A paper presented at the National Technical Conference of the Illuminating Engineering Society, September 12-16, 1955, Cleveland, Ohio. AUTHORS: Day-Brite Lighting Inc., New York, N. Y. and St. Louis, Mo. respectively.

Uplighting

Just a few years ago the lighting profession began emphasizing the importance of "uplighting" in industrial areas; that is, sending upward to the ceiling, a certain component of the light emanating from a luminaire. In a paper presented at the I.E.S. National Technical Conference in Chicago in 1952, the authors pointed out the undesirable or "discomfort" results of totally direct (all downward light) fluorescent luminaires. These lumi-

naires in effect were at that time the standard for industry. Since then a new *standard* has been set and accepted. Luminaires with all downlighting have given way, thank goodness, to designs providing reasonable upward components of light. In our opinion, wide application of this will result in relief, at last, of strain and seeing discomfort in industry.

Analyses described in the 1952 paper showed significant improvement in comfort of seeing with luminaires having 5 to 15 per cent of their light directed upward. At that time, three experimental designs with higher upward components were studied and showed substantial improvement in comfort of seeing. Today *standard* units with uplighting are available for 5 to 15 per cent and 20 to 30 per cent ranges. Analyses of these standards will be the basis of the present paper, with further emphasis on comfort of seeing.

Factors Influencing Seeing

While the factors influencing easier and more comfortable seeing are well known, they nevertheless are not widely applied. The first factor is illumination level — "*footcandles.*" In this regard I.E.S. Recommended Practice is quite generally used and accepted. Second, brightnesses — or the *footlamberts.* This is more often talked about but not applied to specific seeing tasks in industry. Third, *brightness engineering,* which in plain language is a balance of footcandles, footlamberts and interior finishes. This third factor in comfort of seeing is a matter of grave importance, though sadly misunderstood and consequently often neglected. A further purpose of this paper will be to show the necessity of proper brightness engineering, and its relation to seeing comfort.

Luminaire Types Analyzed

While there are many combinations of fluorescent luminaires worthy of study for industrial application only those types most commonly used are presented in Table I. These comprise 15 types and for purpose of easy comparison are divided into three categories:

(1) Group I—Solid top reflectors with all light directed downward. Luminaires are designed for nominal 8-foot channel lengths for two or three T-12, 75-watt (slimline) lamps and four or six T-12, 40-watt (rapid start) lamps. For T-17, 90-watt (fluorescent) lamps nominal 10-foot channels are used.

(2) Group II—Slotted top reflectors in the 5 to 15 per cent uplight classification and the remaining light directed downward. Luminaires are designed for channel lengths and lamps as in Group I.

(3) Group III—Slotted top reflectors in the 20 to 30 per cent uplight classification and the remaining light directed downward. Luminaires are designed for nominal 8-foot channel lengths for two T-12, 75-watt (slimline) or two T-12, 100-watt (rapid start) and four T-12, 40-watt (rapid start) lamps.

Lighting Calculations

As indicated in Table I, a room size was chosen to give a "room index" of "A," *i.e.* 60 feet by 120 feet. Luminaires are mounted 10 feet above the floor. The height of the ceiling is considered to be 14 feet.

Illumination computations were made for the 15 types of lighting systems using the lumen method to provide 50 footcandles maintained. The conditions and general factors applying to these computations are shown in Table I. An operating rate of 4000 hours per year was used in determining annual operating costs with the power rate of 1½¢ per kwh.

All coefficient of utilization values were computed specifically for each condition of room reflectances from photometric data for each luminaire.

The upward component of light for Group II and III luminaires is shown in Table I as "luminaire distribution." The values given for uplighting are expressed in percentage of total lumen output. Therefore, the amount of upward and downward light adds up to 100 per cent. The values might have been expressed in percentage of luminaire efficiency. For example, System No. 11 shows 27 per cent uplight and 73 per cent downlight, a total of 100 per cent. It could be expressed as 23.5 per cent uplight and 63.0 per cent downlight or 86.5 per cent which is the "overall efficiency" of the luminaire. It is felt that the former expression has more significance and is easier understood for practical purposes of application.

A point of general interest in illumination computations is that present industry standards for porcelain enamel reflectances have risen about 5 per cent within the past few years. Considerable progress in lamp efficiencies has also been made which affects lighting economics. A comparison of values published in the authors' 1952 paper with those of today is shown below.

	Cool White (Lumens)	
Lamp	1952	1955
40-watt 48" T-12	2300	2500
90-watt 60" T-17	4600	5150
75-watt 96" T-12	4800	5050

TABLE I — Comparison of Industrial Lighting Systems.

Room Size: 60 x 120 — Room Index: A — Luminaires equipped with all white, all porcelain enamel, open end reflectors — Illumination: 50 footcandles maintained
4000 operating hours per year — Luminaires: 10' above floor — Ceiling: 14' high — Worm White Lamps (except where noted)
Power at 1½¢ kwh

Luminaire Classification	Group I					Group II					Group III				
Type Luminaire	1	2	3	4	5 (Note 1)	6	7	8	9	10 (Note 1)	11	12 (Note 2)	13	14	15
	2/90	2/60	2/75	2/60	2/60	2/90	2/60	2/75	2/60	2/60	2/75	2/100	2/60	2/75	2/60
General Data															
No. lamps per section	4 (T-17)	6 (T-12)	2 (T-12)	4 (T-12)	4 (T-12)	4 (T-17)	6 (T-12)	2 (T-12)	4 (T-12)	4 (T-12)	2 (T-12)	2 (T-12)	4 (T-12)	2 (T-12)	4 (T-12)
Luminaire shielding*	14" x 0"	13" x 0"	13" x 0"	14" x 0"	14" x 2"	14" x 0"	14" x 0"	13" x 0"	13" x 0"	14" x 2"	30" x 0"	30" x 20"	30" x 0"	30" x 20"	30" x 20"
Luminaire distribution															
90°-180° (uplight)	0%	0%	0%	0%	0%	11.0%	9.5%	11.0%	11.0%	10.0%	27.0%	30.0%	27.0%	30.0%	30.0%
0°-90° (downlight)	100%	100%	100%	100%	100%	89.0%	90.5%	89.0%	89.0%	90.0%	73.0%	70.0%	73.0%	70.0%	70.0%
Overall efficiency	80.0%	77.5%	78.5%	80.5%	78.0%	86.0%	81.0%	85.5%	85.5%	82.0%	86.5%	78.2%	86.5%	78.0%	78.0%
Maintenance factor	.65	.65	.65	.65	.65	.70	.70	.70	.70	.70	.70	.70	.70	.70	.70
Coefficient of utilization															
Room reflectances** 75/50	73	71	72	73	72	74	74	74	74	72	71	84	71	84	84
" " 50/30	69	67	68	69	68	70	68	69	69	67	64	56	64	56	56
" " 30/30	68	67	67	68	67	68	66	67	67	65	60	53	60	53	53
" " 30/10	67	65	65	67	65	66	65	65	65	64	58	51	58	51	51
Number luminaire sections															
Room reflectances 75/50	36	50	76	73	84	33	45	68	67	78	71	59	70	79	78
" " 50/30	38	53	80	78	89	35	49	73	72	84	79	68	78	90	89
" " 30/30	39	53	81	79	91	36	50	75	74	87	84	71	83	95	94
" " 30/10	39	55	84	80	93	37	51	78	76	89	87	74	86	99	97
Watts per sq. ft.															
Room reflectances 75/50	2.18	1.97	1.86	1.97	2.22	2.09	1.78	1.67	1.80	2.06	1.74	1.97	1.93	1.93	2.08
" " 50/30	2.31	2.10	1.96	2.08	2.35	2.04	1.92	1.79	1.94	2.22	1.93	2.28	2.08	2.20	2.39
" " 30/30	2.33	2.10	1.99	2.11	2.39	2.45	1.97	1.83	1.99	2.28	2.06	2.37	2.22	2.32	2.53
" " 30/10	2.36	2.15	2.06	2.14	2.46	2.24	2.02	1.90	2.05	2.35	2.13	2.47	2.31	2.42	2.61
Cost Data (75/50)															
First cost including lamps	$3,544.	$3,686.	$4,483.	$4,551.	$5,625.	$3,216.	$4,337.	$4,031.	$4,376.	$5,222.	$4,418.	$4,887.	$5,003.	$5,722.	$6,368.
Per cent (of Type 1)	100%	104%	126%	128%	159%	91%	93%	114%	118%	147%	125%	138%	141%	161%	180%
Annual operating cost	$1,477.	$1,424.	$1,502.	$1,516.	$1,751.	$1,339.	$1,269.	$1,329.	$1,376.	$1,605.	$1,423.	$1,563.	$1,521.	$1,684.	$1,782.
Per cent (of Type 1)	100%	96%	102%	103%	119%	91%	86%	90%	93%	109%	96%	106%	103%	114%	121%
Annual maintenance cost	$63.45	$69.00	$88.20	$100.30	$115.05	$47.40	$67.50	$62.70	$75.90	$87.75	$79.60	$84.20	$93.20	$112.60	$127.00
Per cent (of Type 1)	100%	140%	139%	158%	181%	75%	106%	99%	120%	138%	125%	133%	147%	177%	200%
Cost per sq. ft.															
First cost	$.49	$.51	$.62	$.63	$.78	$.45	$.46	$.56	$.58	$.73	$.61	$.68	$.70	$.80	$.88
Annual operating cost	$.21	$.20	$.21	$.21	$.24	$.19	$.18	$.18	$.19	$.22	$.20	$.22	$.21	$.23	$.25
Comfort Data (75/50)															
Glare factors															
Crosswise	155	235	140	145	145	130	130	100	100	100	30	30	30	25	25
Lengthwise	150	275	125	130	130	140	130	95	95	95	70	35	70	35	35

*Luminaire shielding: First figure denotes crosswise shielding; second figure lengthwise shielding.
**Room reflectance: First figure denotes ceiling reflectance, second figure wall reflectance.

Note 1 — Based on 1952 costs with closed end reflectors and cool white lamps.
Note 2 — Computations based on cool white lamps.

TABLE II.

Lamp	Ballast	Warm White (Lumens)	Average Life (Hours)
40-watt 48", T-12	Rapid Start	2600	7500
75-watt 96", T-12	Series	5100	7500
100-watt 96", T-12	Rapid Start	6800*	7500
90-watt 60", T-17	Tulamp	5300	7500

*Cool White (not listed in Warm White).

In 1952 the currently listed 90-watt lamp was an 85-watt lamp. Commercial type fluorescent lamps in 1952 had a rated life of 7500 hours, except slimline which was 6000 hours. Since then, slimline lamps also have a rated life of 7500 hours.

Average published values for lumen output and life of lamps used in the illumination calculations in Table I are as shown in Table II.

The assignment of maintenance factors for various luminaires is based on experience and tests reported in the United States and the United Kingdom. Slotted or ventilated top reflectors show improved maintenance performance. Unfortunately, there is not yet sufficient evidence to establish still better maintenance with larger apertures, as with Group III luminaires. Consequently, Group II and III maintenance factors have been assigned the same values.

Cost Data

Costs are based on a typical factory area representing construction features to be found in average sized buildings.

Computed costs are based upon an in-service level of 50 footcandles. Branch circuit wiring costs are included in the comparative cost results shown in Table I. These costs are based upon two 3-phase 4-wire distribution centers in the 60-foot by 120-foot room and 120-volt circuiting to continuous rows of luminaires for the various lighting systems. Included in the wiring costs are the cost and installation of lighting panel boards, branch circuit wiring in conduit to luminaire channels and wiring connections to each luminaire.

Perhaps mention should be made here of 480/277-volt distribution systems which point the way toward definite and substantial cost savings in large plant construction. Ballasts for 277-volt are readily available for conventional size fluorescent lamps, as are wiring accessories and switching devices for these circuits. This paper, however, covers only 120-volt distribution by virtue of the fact that average size buildings almost universally use this service.

The installation of luminaires in their proper location includes cost and installation of mounting anchorage points in the ceiling from which luminaires and suspension members are supported. These costs and the cost of luminaires are based upon normal competitive bidding for large factory areas through union electrical contractor purchasing materials and equipment through an authorized electrical distributor.

The installation costs of luminaires are based upon an unoccupied room area. Such costs may be materially higher if machines or other equipment are in place making it difficult or impossible to use and move scaffolding in the room.

Although labor costs keep rising it is interesting to note that lighting costs have been declining. Part of this is due to previously mentioned improvevent in luminaire and lamp efficiencies and longer lamp life. Also the net cost of fluorescent lamps no longer includes an excise tax. Net cost of lamps used in computations is based on a 30 per cent discount from list prices.

All luminaire prices are based on the use of metal clad "push type" lampholders. Since an overwhelming percentage of industrial luminaires are installed with "open end" porcelain reflectors cost studies are based on these designs. Amortization is given at 10 per cent of total luminaire costs (excluding lamps).

Comfort of Seeing

The "crusade" for seeing comfort for working men and women in the world of production is being realized and appreciated judging by many quality lighting systems which have been installed in the past few years. Appraisal of comfort is measured by several methods. One such method, among others recognized and published in the *I.E.S. Lighting Handbook* — Second Edition (1952), is commonly known as the Harrison-Meaker Glare Factor System. Further work has been carried on by Meaker (Cleveland) and Bradley (St. Louis) in making this method more attractive for general application of industrial lighting where comfort is desired.

The glare factor system is, in our experience, as easy to use as utilization tables and for this reason, we feel is particularly desirable for specifiers and users of lighting installations. As an aid in determining comfort ranges a glare factor evaluation chart is given in Fig. 2. Room conditions in terms of reflection factors are ceiling — 75 per cent; walls — 50 per cent; work surfaces — 15 per cent.

It is evident that in many production operations critical visual tasks are encountered for relatively short durations. Such tasks might be found with lathe work, shaping and milling machines, drilling operations, etc., as one phase of industry where

eyes may be required to view the job intermittently. Range *D* of Fig. 2 may well suit the seeing and comfort requirements for these tasks. Less critical or shorter periods of concentration of visual tasks may find Range *E* adequate and suitable. Where working eyes are literally "glued" to visual tasks, such as fine assembly and close inspection, Range *A* may be necessary. Where these specific tasks are less critical and require less continued concentration Range *B* to Range *C* may suffice. It is for the experienced lighting engineer and supervisor of production operations to determine the proper range to use in establishing suitable luminaires that provide appropriate illumination levels and glare factors to fit the job or visual tasks.

It is likely that seeing tasks in the Ranges of *A* and *B* will be encountered in clean, air-controlled rooms. Commercial type luminaires with suitable glare factor ratings under such conditions may be applied. These luminaires generally will have upward components of light approaching 50 per cent and preferably of an all-metal design to withstand the normally rough handling in industrial applications. In the majority of cases for Ranges *C*, *D* and *E*, the more ruggedly constructed porcelain enamel reflectors are used and analyzed in this paper. These reflectors can be washed repeatedly without harm to reflecting surfaces, in almost any factory area.

While it is difficult to set specific limits to the many and varied visual tasks found in industry, a guide in specifying glare factor ranges is shown in conjunction with Fig. 2. In addition, multiplying factors are given for different levels of illumination in determining glare factors for other than 50 footcandles as established in Table I.

Attention is called to the fact that glare factors for any given level of illumination decrease when mounting heights of luminaires increase. Conversely, glare factors increase as luminaire mounting heights are lowered. Also, as room sizes become smaller glare factors become lower. The converse is true; with larger rooms glare factors increase.

Glare factors also increase with higher footcandle levels and decrease with lower levels. In evaluating a lighting system for comfort, the level of illumination for a specific seeing task must be determined. Where 30 footcandles are recommended under certain seeing conditions, glare factors (for example in System No. 11) would be around 25 crosswise and 55 lengthwise, compared with 30 and 70 respectively as shown in Table I for 50 footcandles. However, at 80 footcandles (for instance, where critical seeing tasks prevail, requiring System No. 14), it will be noted that these glare factor values, 25 crosswise and 35 lengthwise, increase to 30 and 40 respectively. Similar comparative reasoning applies to other systems presented in Table I. Small differences in numerical values of glare factors in ranges shown in this paper are not construed as resulting in significant comfort differences. Consequently, glare factors have been rounded off to customary values used in practice. This should not be taken loosely, and where comfort is a consideration, the choice in the direction of lower values is recommended rather than toward higher values even in a given range.

It is interesting to note that System No. 12, using 100-watt rapid start lamps, compares favorably in glare factor rating with System No. 14 using 75-watt slimline lamps. The brightness of the rapid start lamp is 2500 footlamberts compared to 1900 footlamberts for the slimline lamp. For this reason, it might appear that there should be some recog-

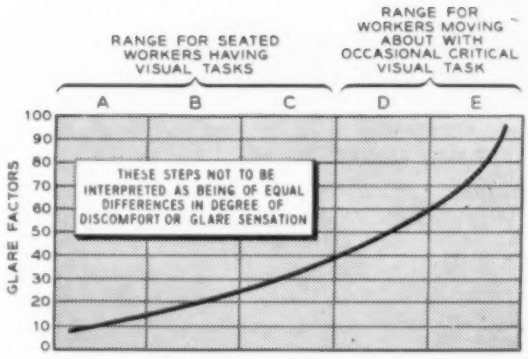

Figure 2. Glare Factor Evaluation Chart. Comfort conditions relating to production activity in each range of curve are:

Range	*Ft-c* Over	*Classification*
A-B	100	VERY DIFFICULT SEEING TASKS Very fine assembly and inspection — finest precision work — poor contrast — long periods of time — workers in one position.
C	100	DIFFICULT SEEING TASKS Close assembly and inspection — fine precision work — fair contrast — long periods of time — workers in one position.
D	50	CRITICAL SEEING TASKS Average assembly and inspection — fine detail work — moderate contrast — intermediate periods of time — workers not seated in one location.
E	30	ORDINARY SEEING TASKS Moderately fine detail — normal contrast — short periods of time — workers moving about.

Multiplying Factors For Other Footcandle Levels						
Footcandles	30	40	50	60	80	100
Multiply By:	80	90	1.00	1.10	1.20	1.30

nized difference in comfort. The reason this is not true is due to the higher lumen output of the rapid start lamp which requires *fewer* luminaires to provide the prescribed 50 footcandles. The glare factor system accounts for the difference of a given number of projected brightnesses of luminaires and overall brightness patterns within a room area. Where reflected glare from glossy or highly polished surfaces presents a problem and cannot be avoided by workers, the lower brightness lamps are naturally to be desired regardless of installed costs.

The high output rapid start lamp is shown in Table I, System No. 12, with louvers only. This does not preclude its use in luminaires without louvers. Its omission in this form is merely a matter of space. In general, however, its greatest application without louvers will be for higher mounting heights and with louvers for low ceiling areas.

Comparing Lighting Systems

Some years back there was a predominant use of "cost comparisons" with prime emphasis on cost. There were two prevalent factors influencing the choice of a lighting system (1) first cost and (2) operating cost. Occasionally if first cost was notably lower in one system it was accepted without further study. Frequently higher first cost systems were installed if operating costs were favorable to the higher cost systems. Generally higher first costs were approved if the operating costs would pay off within a five- or six-year period. In those days more attention was paid to dollars than to comfort. How gratifying it is that the trend is now much more in favor of comfort rather than costs, high or low. And why not? Certainly it has been proven time and again that workers who can see comfortably produce more manufactured goods in less time, and are happier with working conditions. There is far less skepticism today in the value of quality of lighting in terms of investment and return.

Comparative *first costs* are graphically shown in Fig. 3 for all lighting systems studied in this paper. The data shown are for installed costs per square foot. The values obviously will not apply specifically for every city in the country although relative differences should be reliable enough to guide specifiers and users to the proper choice of a lighting system. It must be realized that costs are based on certain conditions of structure and room size (60 feet by 120 feet). For rooms which are larger in size, the cost per square foot may be slightly lower and for smaller rooms, somewhat higher.

A quick glance at Fig. 3 will reveal that Group I luminaires in the all downlight classification are more expensive than Group II luminaires, those in the 10 per cent uplight bracket. Quite aside from this, the Group II are far more comfortable. No wonder the swing is overwhelmingly in favor of Group II over Group I since our 1952 paper.

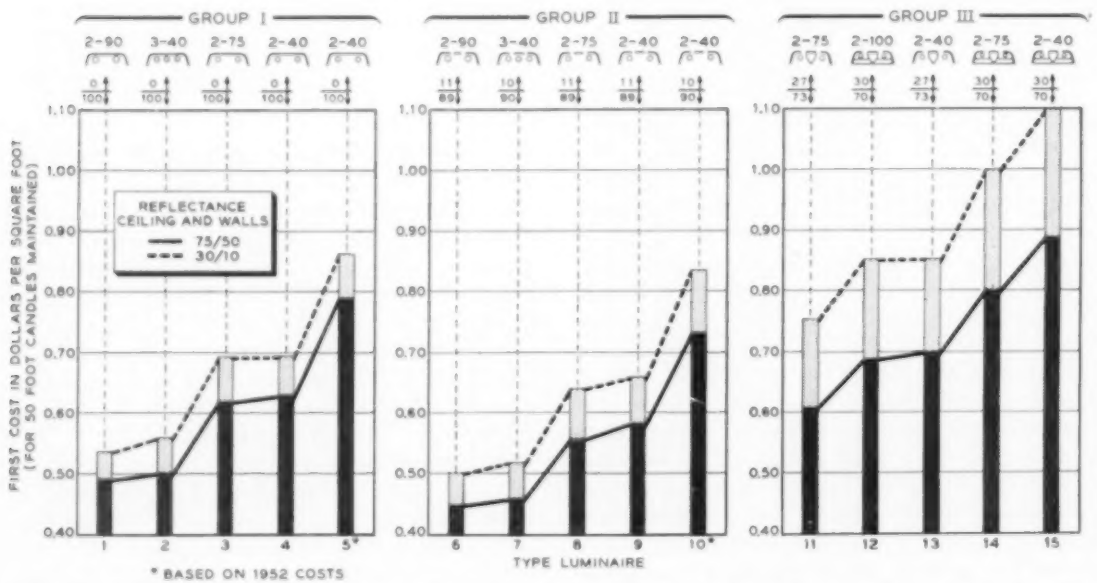

Figure 3. Average first cost per square foot for typical industrial type luminaires to produce 50 footcandles (maintained). Lighting cost includes local panel boards and wiring to installed luminaires.

For purposes of general interest, Table I and Fig. 3 show two luminaires (Types 5 and 10) published in 1952 in comparison to similar luminaires (Types 4 and 9) of current design. The 1952 luminaires had closed-end reflectors in contrast with the more popular reflector of today with "open ends." Unique designs in construction permits open-end porcelain enamel reflectors today by virtue of rugged construction that was not available previously.

While *color of light* will always remain a matter of opinion with individuals, present costs are based on the more efficient fluorescent warm white lamps rather than cool white as in 1952. With these specific considerations, the cost of System No. 9 (1955) at 58 cents per square foot effects a substantial saving over the 73 cents per square foot (1952). Indeed, a 20 per cent saving is substantial. Not to be overlooked is a further saving in the use of slimline lamps over rapid start lamps (System 8 *vs* 9). A more pronounced saving in this connection is realized in comparing Group III luminaires (System 11 *vs* 13).

Room Finishes

In spite of past arguments (a few still persist) the use of light finishes on ceilings, walls, floors, bench tops and machinery is recommended and should be used where practicable. The reflectances should be consistent with those recommended in the "American Standard Practice for Industrial Lighting."

The significance of light room finishes is readily apparent from Fig. 3. To obtain equal illumination levels the costs are somewhat higher when reflectances are lower than the recommended minimum range of 75/50. In the Group II luminaires, costs are over 10 per cent higher for 30/10 room finishes than 75/50. For Group III luminaires, the cost differential is over 20 per cent higher. The reason for this is simple — coefficients of utilization decrease with poorer room finishes and the required number of luminaires increase as indicated in Table I.

The *first costs* plotted in Fig. 3 are for two conditions of room reflectances — 75/50 and 30/10. For other room finishes between these values the costs will vary proportionately between the limits of the two curves drawn.

While light finishes throughout a room lower lighting costs, this is by no means the governing factor in providing such finishes. The more important aspect is in eye comfort gained in properly balancing brightness ratios as exemplified in Figs. 1 and 4. Recommended brightness ratios are listed in the "American Standard Practice for Industrial Lighting."

When luminaires are suspended below ceilings, as is the case with the majority of industrial applications, Group II or III luminaires should be used. Which of the two groups to use depends upon room conditions and the severity of the seeing task. It is evident that Group I luminaires casting all light downward account for dark, gloomy ceilings (Fig. 1) resulting in poor brightness ratios, discomfort and higher *first* and *operating* costs.

There are many production areas in industry where seeing tasks are more acute than in offices. Yet in these production areas quality lighting and other factors affecting employee comfort were not

Figure 4. Troffer (all downlight) has a modern look and comfort too when interior finishes are light in color resulting in good brightness engineering. Note other comfort aspects as with air-conditioning and acoustical ceiling.

always considered as important as in offices. One prime reason for this in the past was that commercial areas were cleaner than in most factories and maintenance was not considered as great a problem. Today there are many production areas with clean atmospheric interiors. Very often these areas require cleanliness together with temperature control in the production or assembly of certain manufactured parts.

Modern plant lighting frequently has turned to the use of recessed troffers with all downward light. In addition, air-conditioning is provided as well as acoustical treatment of ceilings. Where troffers are used, it is highly important that room finishes, including floors and machinery, have suitable reflectances. Current practice is to select pastel colors for a cheerful room appearance. Various colors are used with particular attention given to the use of cool or warm colors befitting the class of production performed. The proper choice of colors has an important bearing on the psychological reaction of working people.

Depreciation Tests

Tests have been conducted by numerous investigators on luminaires to determine the loss in output with solid top reflectors and slotted top reflectors. Results prove that reflecting surfaces depreciate at a slower rate with ventilated reflectors than non-ventilated reflectors. As previously mentioned, there is no substantiating evidence to indicate that Group III luminaires with larger reflector apertures, depreciate at a slower rate than Group II luminaires with smaller apertures.

In order to study the effect of accumulated dust and dirt on lamps and reflectors, the authors conducted a test on several types of luminaires analyzed in this paper. The luminaires were installed in a welding shop where day-shift operations took place. The units burned continuously for a period of three months. After that period, they were removed and photometered. Then they were carefully washed and photometered again. The results are tabulated in Table III.

Although tests were made with 40-watt rapid start fluorescent lamps it is expected that 75-watt slimline lamps would perform similarly. However, there appears to be a faster depreciation rate with 100-watt rapid start lamps in the same type of reflector. It is possible that the 100-watt lamps operate at higher temperatures than the 40-watt and 75-watt lamps which may have some effect on air currents and dust deposit on reflecting surfaces.

Luminaires with larger slots (nominal 30 per cent uplight) or with more ventilation perform better than those with smaller slots (nominal 10 per cent uplight). Non-ventilated reflectors are proportionately less favorable from a maintenance standpoint.

The purpose in starting these depreciation tests was to further justify the assignment of maintenance factors in Table I. It is obvious that a three-month test cannot be expected to give conclusive results from which specific maintenance factors can be determined. Nevertheless they do indicate the value of ventilation with better maintenance performance. These tests are being continued in the hopes that more reliable information may become available.

TABLE III — Rate of Depreciation of Porcelain Enamel Reflectors.

Luminaire Classification		Luminaire Efficiency		
Type of Unit	Nominal Uplight	Clean	Dirty	Per Cent Depreciation
2-40-watt	30%	83.7%	74.5%	11.0%
2-100-watt	30%	78.8%	69.9%	11.3%
2-40-watt	10%	86.5%	76.5%	11.6%
2-40-watt	0%	85.4%	74.6%	12.6%

Maintenance

No matter what the atmospheric condition of a room interior may be, there is no dodging a maintenance program. No set rule can be prescribed in following a maintenance schedule, because of the varying conditions in industry. The *maintenance factors* listed in Table I are in effect for a specific condition. They are well chosen for average plant conditions. Yet, they may be higher in value for clean, air-conditioned rooms but lower in dusty, oily machine shops.

The choice of a maintenance factor determines in reality the frequency of cleaning or washing of luminaires. Slotted top reflectors have been found to depreciate in light output less than solid top reflectors. To maintain the same average level of illumination Group I luminaires would require washing at a frequency of about 1½ times a year or something like once every nine months. Group II and III luminaires are based on a once-a-year washing schedule.

In Table I the *Annual Maintenance Cost* includes cleaning or washing costs and labor to replace burned out lamps. Some worthwhile savings are realized with slotted top reflectors compared with closed top.

Strength and durability of industrial luminaires is of vital importance in low cost industrial maintenance over the life of the installation. Lumi-

naires included in the analysis for regular industrial applications, are all-metal, sturdily and strongly constructed, using channels to house ballasts and metal-clad lampholders, with detachable all-white, all-porcelain reflectors. These features are strongly advocated for factory areas and especially the porcelain enamel reflector with its hard glass-like surface which can be repeatedly washed without harm to its reflecting surface.

Considering the overall economy of maintenance it would be remiss if mention were not made of the advisability of following a "group relamping" program. This subject has been widely discussed in recent years and many industrial users of lighting have high praise in advocating its adoption.

Since luminaires with uplighting have essentially replaced those with no upward light another form of maintenance requires more attention than in the past. Ceilings must be white and kept white by repainting at proper intervals. If ceilings are not properly maintained with Group III luminaires, a substantial reduction in light output may result due to absorption. Group II luminaires are less affected by ceilings "darkened" with age, but dark ceilings, with any type of luminaire, produce undesirable brightness ratios, and accompanying discomfort. Similarly other room finishes must be given proper attention at regular intervals if high eye comfort, satisfied employees and production efficiency are to be maintained.

Acknowledgments

Again the authors are indebted to many people and organizations of wide industrial and production experience who devoted time and support in supplying information for use in this paper. Mr. R. W. Osborn, Osborn Electric Company, Electrical Contractors and Engineers, St. Louis, was especially cooperative in providing installation cost data.

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DISCUSSION

WILLARD ALLPHIN:* The authors have given us another of their thoughtful papers in which they compare the estimated costs of various lighting systems designed to deliver the same number of footcandles. In this case they have included glare factor calculations for the systems under study.

There is always the danger of falling under the "magic spell of numbers" when glare factors or other ratings are used in this way. One tends to accept 32 as being better than 34, forgetting that the range of error in the process may be much higher than two units.

Note that I say "range of error" rather than the statistician's "probable error." What I mean is this: Suppose a glare rating formula has the square of a brightness in its numerator and the projected area of a fixture in its denominator. If we measure the brightness of a particular fixture in a particular direction and find it to be 2150 footlamberts, this may mean that the value is somewhere between 2100 and 2200 footlamberts.

Also, if we compute the projected area at a particular angle to be 630 square inches, it may actually be somewhere between 620 and 640. Therefore we should work the problem once using 2100 squared in the numerator and 640 in the denominator, then work it again with 2200 squared in the numerator and 620 in the denominator.

Actually the other terms in the equation have ranges of error also, so that if we established a range for the whole equation, a glare factor might look something like 27 ± 4. We therefore could not say with any certainty that this was better than one of 30 ± 5.

The authors have taken a commendable step in rounding

*Sylvania Electric Products, Inc., Salem, Mass.

off their calculated glare factors, thus implying a range of error, but I hope that it may become the practice to use an actual plus or minus value in such work to remind us of the approximations involved.

E. A. LINSDAY:* Papers on the comfort of industrial lighting systems have been very few. More work and educational material certainly is desirable in this field. The authors are to be congratulated for developing a paper on this subject, which delves rather thoroughly into this phase. It is hoped that this paper will add to industry's consciousness of the importance of comfort in the design of a lighting system, and give comfort its proper weight among the other considerations — that is, cost, maintenance, lighting level, reflected glare, etc.

The data in Table I on "Cost" points out clearly how economical it is to provide comfortable lighting. The main reason for the favorable economics, as the authors indicate, is the improved maintenance of the fixtures with upward light. We agree with the authors in that more work is needed to determine just what the improvements in maintenance are with these fixtures. As the authors indicate, the tests that they ran over a period of three months cannot give conclusive results. Therefore, it is probably better not to draw definite conclusions from these data yet, but to wait until the tests have progressed farther so that greater accuracy can be obtained. The difference in per cent depreciation between the 40-watt fixture, which was 11 per cent, and the high-output rapid-start fixture, which had a depreciation of 11.3 per cent, is not of sufficient magnitude to be significant, especially when this difference is probably less than the accuracy of the photometry involved. However, the maintenance factors that the authors used for the difference between ventilated and non-ventilated units are of the magnitude we would expect from limited data that we have obtained.

The authors point out the importance of room finishes in lighting systems. This touches on factors which are too often neglected — that of providing light room surfaces for two reasons: to increase the coefficient of utilization, and to reduce brightness contrast thereby increasing comfort.

The costs shown in Table I agree quite well with cost analyses which we have done. A few of the aspects of the cost data are not clear; for example: (1) Does the amortization of 10 per cent per year include insurance and taxes and interest? (2) Are both luminaire and installation cost included in the amortization? (3) Does the annual operating cost include the maintenance cost?

Since many people are familiar with VCI, *i.e.*, Visual Comfort Index, I took the liberty of converting the authors' glare factors for the various lighting systems to VCI. (VCI (Visual Comfort Index) indicates the percentage of people that would be expected to judge a particular lighting system as comfortable when they view it while seated at a point near the middle of the back wall.) (See Table.) The authors indicate that the Group II luminaires are much more comfortable than Group I luminaires, and therefore the swing has been overwhelmingly in favor of Group II luminaires. However, a glance at the VCI Table shows that Group III luminaires, that is, those with 20-30 per cent upward light, have an even more startling improvement in comfort. For this reason we feel that the swing has been towards Group III luminaires rather than Group II luminaires.

It should also be pointed out that a white exterior fixture finish is one of the reasons for the improved comfort of the new type of fixtures, since it helps to reduce brightness contrasts between the inside and outside of the fixtures.

One of the strongest arguments for comfort in industrial lighting can be obtained from the table of data in this paper. In Column 12, the authors have listed the 96T12 high-output Rapid Start lamp. This lamp is listed in standard cool white color, while the rest of the systems use standard warm white lamps. To put them on the same basis, therefore, the high-output rapid start system should be reduced in cost a few per cent. If this is done we find that a high-output rapid start fluorescent installation with 30 degrees x 20 degrees shielding can be obtained at about the same total overall cost as a slimline system with closed top reflector as of Group I. Therefore, for the same cost a lighting system is obtained which has a VCI of 76 per cent in crosswise viewing and 71 per cent in lengthwise viewing, compared to 7 per cent and 10 per cent respectively for the standard system. This is truly progress. I believe the authors pointed this progress out quite clearly when they said that although labor costs have increased in the past few years, lighting costs have been reduced due to improvements in lamps and luminaires, which enables the consumer to obtain more comfortable lighting systems at no additional costs.

PHELPS MEAKER:* People have been kind enough to link my name with that of Dr. Ward Harrison in connection with glare factors; the term step-father has been applied to me. It is very gratifying to see this means of comfort analysis applied in so conspicuous a paper. The fact is that glare factors are growing in their sphere of influence without need for much help from even a step-father. But I cannot refrain from adding a remark at times, hoping to aid in the understanding of exactly what they represent.

Upward light in a lighting installation results in a more favorable glare factor or VCI rating because the high con-

*General Electric Co., Nela Park, Cleveland, Ohio.

*General Electric Co., Nela Park, Cleveland, Ohio.

TABLE (Lindsay Discussion).

LUMINAIRE CLASSIFICATION	GROUP I					GROUP II					GROUP III				
TYPE LUMINAIRE	1 2/90	2 3/40	3 2/75	4 2/40	5 2/40	6 2/90	7 3/40	8 2/75	9 2/40	10 2/40	11 2/75	12 2/100	13 2/40	14 2/75	15 2/40
Glare Factors															
Crosswise	155	235	140	145	145	110	120	100	100	100	30	30	30	25	25
Lengthwise	150	275	125	130	130	140	130	95	95	95	70	35	70	35	35
Visual Comfort Index															
Crosswise	*	*	7	6	6	14	11	18	18	18	76	76	76	81	81
Lengthwise	5	*	10	9	9	7	9	21	21	21	37	71	37	70	70

*Less than 5.

trast between the bright interior of an opaque reflector and its immediate surroundings is reduced. The element of contrast is established between the interior brightness and either the ceiling above the installation or the exterior of the reflectors themselves, whichever is the lower value of the last two. The point I want to emphasize is that unless the exterior is white there will be little credit given for upward light. The latter must be reflected from the ceiling, strike the outside of the reflector, and from there be directed to our eyes to serve in relieving this contrast. Therefore, reflecting ceilings *and* white exteriors are essential in making the upward light pay off in terms of comfort.

It has been mentioned that the lumen rating of the lamps for which the table is constructed may not be the same as the lumen rating of the lamps installed, and accordingly the luminaire brightness encountered in practice. I am glad to be able to suggest a correction factor. If we assume that when higher output lamps are employed, the design will use, at least theoretically, a smaller number of fixtures to obtain the specified illumination level, the glare factor will increase in direct ratio with the brightness. If 2500-lumen lamps are used in a luminaire whose glare factor table was based on 2300-lumen lamps, the rating figures should be raised by 8.6 per cent. In terms of VCI, tabular values corresponding to 50 footcandles should be replaced by values found from a correction to a 62-footcandle basis.

On the other hand, it may be assumed that an installation put in to provide 50 footcandles in service, employing 2300-lumen lamps, is now being equipped with 2500-lumen lamps. What is the result upon glare factor of the increased brightness, taking into account the effect of the brighter environment resulting from the increased footcandle level? Here the answer is a little different. Let us merely record the increases in glare factor corresponding to 5, 10, 15 and 20 per cent increases in lamp and luminaire brightnesses. The glare factors will be increased by 7.8, 15, 22.5 and 30 per cent respectively for the changes assumed above. In terms of VCI, the changes are equivalent to correcting the footcandle basis from 50 to 60, 71, 83 and 96 footcandles, respectively.

GERALD MARKS:* Papers of this type which deal with the application end of Illuminating Engineering are indeed helpful to engineers such as myself who deal with the user of lighting equipment.

As in any paper that involves the use of figures, figures that vary in parts of the country, and figures that vary with engineers, could be questioned. However, no one can argue with procedure.

I might point out, however, that in my experience in the use of VCI as against Glare Factors, the people I have dealt with seem to be able to understand the meaning of VCI better than Glare Factors. This may be due to the fact that VCI is an easier concept to explain.

My only criticism is not directed at the paper, but rather at the Illuminating Engineering Society. I bring it up now because fundamentally speaking maintenance is a problem of economics or at least affects economics.

My protest is that there is no clear definition of maintenance factors by the IES. As Willard Allphin has pointed out in his letters published in ILLUMINATING ENGINEERING (p. 30A, July IE; p. 8A, September IE) are we talking about the lowest lighting level that a lighting system will reach or are we talking about the average over a period of time, when we talk of a maintained lighting level? If the latter is correct, we then recognize that when we recommend 30 footcandles for a school room, there are times when there are perhaps only 20 footcandles in the room.

I ask that the IES Committee on Maintenance in the near future set up a clear concise definition of maintenance factor.

W. V. C. FOULKS:* One of the interesting points brought out in this paper is that for systems where the indicated initial costs and operating costs are almost equal, in other words where the economic factors are about the same, we are able to compare the relative comfort of systems giving various proportions of upward and downward lighting.

For example, in two systems which utilize the same 8-foot slimline lamps the one having a high indirect component has a Glare Factor crosswise of 30 in place of 140 for the luminaire with no upward light.

The authors have recorded the comfort data in terms of Glare Factors, but I feel that Visual Comfort Index numbers have more significance. The change from Glare Factors to VCI figures is easily made by reference to a published curve or chart.

In terms of VCI, 76 per cent of the people viewing the system with a high indirect component and a Glare Factor of 30 would find it comfortable, against 7 per cent of those looking at the system with no indirect component. Both sets of figures are for the position in the room from which the installation would be least comfortable.

The introduction of louver fins increases the VCI from 76 to 81 crosswise and from 37 to 71 lengthwise. That is, about twice as many people would find the cross louvered units with upward component comfortable when viewed lengthwise as the similar unit without cross louvers.

The authors have indicated Glare Factors for the 100-watt rapid start lamp system the same lengthwise and only slightly higher crosswise than for the 75-watt slimline in the same luminaire. I believe the Glare Factor for the 100-watt rapid start system should be about 30 per cent greater than for the 75-watt slimline, for while fewer luminaires are needed the Glare Factor will increase in proportion to lamp brightness or lumen output when used in the same luminaire.

A final word: it is desirable that those of us who use Glare Factors or VCI numbers or other data based on photometric tests indicate in the tables or charts the lumen output of the lamps on which the data is based.

The authors are to be complimented on giving us this useful analysis of costs and comfort.

J. W. BATEMAN:** I like cost analyses not so much because of the conclusions or figures at the end of the tables, but because they are the means of discussing the merits of different lighting systems with the user, or the consultant, specifying the lighting installation.

Costs and return on investment are foremost considerations in production planning, so when you say "let's make a cost analysis of the different systems which might be used" — right away you have attention. The first thing a user wants to know is how many fixtures to light the area and what they will cost.

A cost analysis muddies this up a little, and gives one a chance to discuss other important aspects of the lighting.

The authors appreciate this, and have combined Visual Comfort, Cost Analysis, and Production Lighting — a good triumvirate. Many factors are important as well as costs.

*Electro Silv-A-King Corp., Chicago, Ill.

*Curtis Lighting, Inc., Chicago, Ill.
**Canadian General Electric Co., Toronto, Ont.

I have no comment on the figures. I have every confidence in the authors to use the slide rule correctly. Actually, the figures in the paper have to be general and do not mean too much when it comes to the consideration of a particular job. The figure applying in a particular case must be used.

They have pointed out the limitations of the figures and emphasized comfort, which is a fine thing.

Of course, up-lighting is good. It is not new. We had it in the Glassteel Diffuser, and the prismatic glass reflectors many years ago.

The new thing is that you can get this up-lighting with fluorescent at no loss in footcandles down below. Percentages of up-lighting mentioned in the paper range from 5 per cent to 30 per cent — quite a variation. I know that the RLM Institute has been doing something about standards. I would like to see one standard for up-light from industrial reflectors, say 25 per cent. To me there is too much variation between different reflectors today. We have heard described a good 150-footcandle job in a factory with reflectors with 10 per cent upward light ("Quality Lighting as Production Booster" by Gordon L. Dovey, November 1955 I.E.). Would the job have been better with reflectors with 25 per cent upward light? I would like the authors' opinion on this.

I differ from the authors on the desirable way of expressing luminaire output. I like actual percentages of light source lumens up and down so they can be added to get the overall efficiency.

FLOYD SELL:* The authors of this paper are certainly deserving of a well earned thank you from the industry for their work in assembling the tangible evidence in the case of "Visual Comfort vs. Gloom in the Factory Shop." It is unfortunate that we are not in a position to make factual statements relating glare factors to operating costs, *i.e.*, for example, a 20 per cent improvement in glare factor is worth a 5 per cent increase in operating cost. If we could do that I believe you would agree that this paper would have far reaching significance.

For reasons of simplicity and brevity I have singled out two fixtures from the list contained in Table I for discussion. They are fixtures #3 from Group I and fixture #11 from Group III. Both use two 75-watt lamps. Since this paper deals with comfort, and the fixtures of Group II (5 to 15 per cent uplight and 13-degree shielding) provide very little visual comfort, I have chosen not to include them in the discussion. I believe their greatest advantage is in the self-maintenance feature.

Taking the data in Table I — as you compare item for item it becomes clear that the advantages are in favor of the Group III fixture in the far column which has a 27 per cent upward component.

Pausing for just a moment on item #4 I would like to express the opinion that there should be a greater difference in maintenance factors in favor of the Group III fixture. And I would also like to comment on the authors' depreciation test procedure although I realize that they did not use these data in this cost comparison. They reported that they burned the lamps continuously for a period of three months in a welding shop where a one-shift operation per day took place. I would just like to point out that burning the lamps continuously had little effect on the results because when work ceases in this kind of a shop the air clears up in a surprisingly short time and is therefore not available to deposit on lighting fixtures.

The balance of the items have a debatable feature in common and that is, room reflectance. How practical is it to provide a ceiling of 75 per cent reflectance and a 50 per cent sidewall? I have not repeated it here but the authors have clearly shown in "watts/square foot," and "number of fixtures required," the economic penalty for not doing so when visual comfort is at stake. Perhaps the savings realized in items 9 and 10 could be put to good use in maintaining those reflectances so that the comfort indicated in item 11 would be a year around reality.

The type of fixture studied, *i.e.*, #11 in Group III is I believe very practical for industrial use. Viewed lengthwise it has a glare factor of 70 which may be too high for some installations in which case another fixture may be chosen with cross baffles to reduce that rating to 30.

The consideration of louvers in a shop area is sometimes viewed with alarm because of the contemplated maintenance problem.

G. G. RAE:* The authors have very properly extended modern ideas of seeing comfort to the important field of industrial operation. A growing recognition of the benefits of comfortable lighting in highly skilled and highly paid industrial operations will gradually reduce the gap between what are now considered typically commercial and industrial units.

An important element in bridging this gap is the use of upward component of light — a method employed for many years in the field of industrial incandescent lighting by the use of prismatic reflectors and now applied to fluorescent open bottom luminaires by the use of slotted openings.

The authors make proper reference to the various factors affecting comfort in industrial lighting and, by a convincing comparison of systems #12 and #14, show that luminaire brightness is only one of several criteria influencing direct discomfort glare.

The writer confirms the authors' statements on the superiority of ventilated reflectors over solid types in reducing the amount of dirt deposited upon the reflecting surfaces and this feature compensates to some degree the loss of light by punching slotted holes in the reflectors.

Finally, the authors make clear reference to the superiority of permanent reflecting finishes, such as glass, as a means of conserving the intrinsic initial lighting output. The loss in efficiency, due to reduction in reflecting surfaces after repeated cleanings is not readily perceived directly but results in lowered overall performance per dollar spent which, after all, is the ultimate evaluation of a lighting system.

J. H. MCCULLOCH:** In comparing columns 4 and 9 (similarly columns 5 and 10) I am bothered by the fact that the coefficients of utilization seem to be almost identical (which I would expect) whereas the number of sections required varies by some 8 per cent. Evidently I have become lost in the step between the coefficients of utilization and the calculation of the number of fixtures to be used. Maybe the point would be worth a little elaborating.

RALPH L. BUSH:† I woud like to call attention to a statement made on page 299 of this paper. In the second paragraph it is stated: "Not to be overlooked is a further saving in the use of slimline lamps over rapid start lamps." In the paper, an 8-foot slimline fixture with two 75-watt lamps is compared with an 8-foot rapid start fixture with four 40-watt rapid start lamps. I have checked the cost of two

*Detroit Edison Co., Detroit, Mich.

*Holophane Company, Inc., New York, N. Y.
**Independent Testing Laboratories, Boulder, Colo.
†L. Ralph Bush & Associates, Atlanta, Ga.

75-watt slimline lamps at $3.50 each and four 40-watt rapid start lamps at $1.25 each. This results in a cost of $7.00 per fixture for slimline lamps and only $5.00 per fixture for rapid start. This may change the cost figures in Table I.

Installing industrial fixtures depends upon the type of construction, and I cannot make a comment on the most practical way of installing them. However, I have used chains and also rods with swivel joint to suspend these types of fixtures, and the result has been good either way.

I have found that slotted fixtures do not get dirty as fast as solid top fixtures and, therefore, require less maintenance. The cheapest and most satisfactory way of keeping fixtures clean is to set up a definite cleaning schedule and to replace all lamps at one time.

J. F. PARSONS:* The authors have brought their painstaking cost and comfort analysis of industrial lighting up to date with a great wealth of pertinent data compressed into a few tables and charts. The conciseness of the presentation should not deceive us as to the amount of work which must have gone into collecting this information. These data present powerful economic arguments for the improved visual environments which are now common in offices and schools, but very scarce in industry. When a better job can be done in 1955 for less money than in 1952 the information should be spread widely.

Fig. 2 causes some misgivings. For some time the proponents of the Glare Factor system have advocated an upper limit of 15 for offices and drafting rooms where occupants are presumably in fixed positions. The curve of Fig. 2 is apparently an interpolation between this value and a nebulous point, the approximate region of which seems to be determined by a general statement:[1] "Observations in factories indicate that the fixture shown (a closed-top, closed-end two-lamp industrial luminaire with central fin) provides lighting of reasonably good quality; hence it may be predicted that glare factors in the range of 50 to 75 will probably be found to represent generally acceptable comfort conditions for industrial-type applications. There is, in most cases, a substantial difference in the type of visual exercise performed by industrial workers, as compared with office or drafting room workers, or school pupils. Accordingly, the limiting value of 15 as previously suggested is no longer applicable. Experience and numerous appraisals will be required to confirm a practical limiting value for factory lighting."

Is this sufficient evidence on which to base the curve of Fig. 2? For ranges D and E it may, or may not, be satisfactory, but ranges B and C involve workers performing "very difficult" and "difficult" seeing tasks, in one position over long periods of time. In offices, such workers would presumably be entitled to an environment with a glare factor of 15 or less, but here a glare rating of 40 is presumed permissible for the same working conditions. Published data[2] on glare ratings indicate that one-third of the workers would be uncomfortable in the least favorable position in such an environment.

Referring to Table I, Group II luminaires show numerically reduced Glare Factors over those of Group I, but when these are converted to VCI ratings, the gains in comfort are scarcely significant. It would appear that only Luminaires 12 through 15 should be used for industrial workers in fixed positions if visual comfort is a criterion.

1. Harrison and Meaker: "Glare Factors and Their Significance," *General Electric Review* (August 1947).
2. Guth, S. K.: "Quality of Lighting," ILLUMINATING ENGINEERING, Vol. L, No. 6 (June 1955).

*Niagara Mohawk Power Co., Buffalo, N. Y.

GEORGE J. TAYLOR and R. D. BRADLEY:* The authors appreciate Mr. Allphin's discussion and feel that he has stressed the point being made in the Group System of glare ratings. The authors feel that trying to use definite and specific numbers for glare ratings is, as yet, carrying the system to its extreme. The general public is very prone to make proportionate comparisons of numbers, which, of course, is not warranted in this case.

Mr. Linsday has asked some specific questions: (1) The 10 per cent-per-year amortization is assumed to cover all items such as insurance, taxes and interest. The authors realize that this may be included as a separate item; however, for the sake of practical illustration, with no definite company's bookkeeping in mind, we have used the 10 per cent blanket coverage. The authors do not feel that this assumption will change the basic conclusions materially, although if specific instances were known, they should be incorporated. (2) Amortization is figured from the total installed cost, which does include labor. (3) The annual operating cost consists of lamp cost, cleaning and relamping labor, amortization and power cost.

The authors agree that the swing in comfort is toward Group III; however, this swing is yet in its infancy and will undoubtedly gather momentum. Group II has been in practical existence for some four years, while Group III has only recently become practical, due to availability of equipment.

Cool white lamps were used in the high-output, rapid-start calculations, as these were the only lamps available at the time. The economics have changed, as outlined by Mr. Linsday.

Mr. Meaker stresses a very good point, which is that the outside of the reflector should be white, or of light color. This is the case in all of these calculations; however, the authors did not make a particular point of it. We thank Mr. Meaker for his suggestion of correction factors which could be applied to the glare ratings shown.

Mr. Marks has brought up the subject of maintenance factor, which the authors realize needs considerable study and clearer definition. The authors have used the term "maintenance factor" in its currently accepted form. It is to be hoped that the work of one of the current IES committees will tend to clarify this situation within the relatively near future.

Mr. Foulks' comments are very well taken; however, the authors feel that there is more confusion in trying to define "per cent of people being comfortable or uncomfortable" than in using an abstract numbering or rating system. Through a typographical error, the louvered unit in Group III, using high-output, rapid-start lamps, should have a glare rating of 33 crosswise and 47 endwise. For all practical purposes, however, this would not materially change the grouping as discussed by these authors.

Mr. Bateman asks if the 150-footcandle job described would not be better if it were to use 25 per cent uplighting in place of 10 per cent. If the reference could be strictly upon a comfort standpoint, the answer would be "yes." The economics would need further analysis, with all facts known, before a definite answer could be given on this point.

The authors agree with Mr. Sell that the maintenance angle has not been fully explored. The authors feel that a great deal more is to be learned and have two field experiments running at the present time, which should reach completion within the next two years. The authors feel that a

*Authors.

great deal of additional information will be gathered at the completion of these experiments.

Mr. McCulloch mentions the difference in number of sections, of approximately 8 per cent, while the coefficients of utilization are about the same for units 4 in Group I and 9 in Group II. The differential is brought about by the difference in maintenance factor, as the authors have allowed five percentage points difference for the open-top versus the closed-top fixture.

Mr. Bush outlines the difference in lamp cost, of the slimline versus the rapid-start, and these same figures were used by the authors in their calculation. The large difference, as shown in our presentation, was brought about due to the difference in cost of the lighting fixtures, which more than offset the lamp differential.

Mr. Parsons' comments on glare ratings are again a good argument for Group Systems rather than absolute numbers. The authors feel that Messrs. Harrison and Meaker have gathered sufficient information to classify fairly well the expected range of discomfort outlined in our Fig. 2. The authors did not intend to convey that they had found, or recommended, the ultimate as far as comfort is concerned, when proposing their Group III type of luminaire. The authors would be the first to agree that luminaires with even more upward component than 30 per cent, and better shielding in both directions, would undoubtedly be necessary where a glare rating of 15 or lower was actually justified. It should also be borne in mind, of course, that where this type of lighting is justified, the complete room environment must also be in keeping to efficiently use equipment with high upward components. Again, the authors feel that the attempt to use per cent of people uncomfortable, as depicted in the VCI System, is rather meaningless, as it does not convey the idea of the amount of correction necessary, without going to the extreme, which, for a great many occupations, is not necessary.

Four Beacons Top the World's Tallest Building

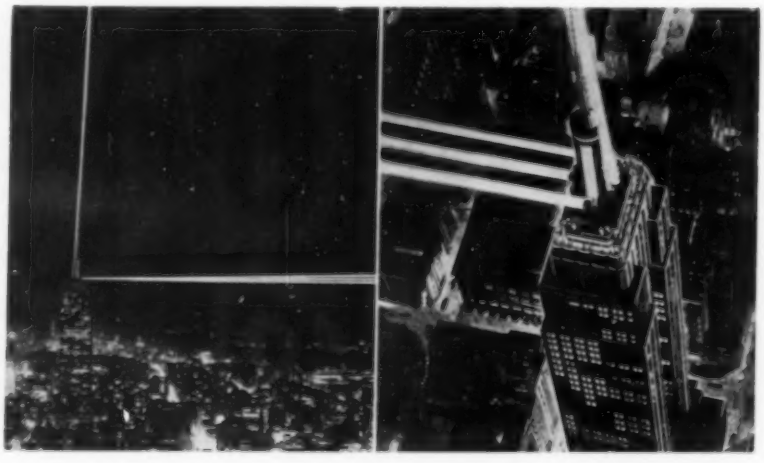
Four beacons, totaling nearly two billion candlepower, mounted at the 90th floor level of New York City's Empire State Building, are expected to be visible from the air, under ideal atmospheric and weather conditions, in a 300-mile arc from the city, according to Colonel Henry Crown, President of the Empire State Building Corp.

The beacons, weighing over a ton apiece, are installed on the four sides of the building, each on a 2200-pound steel frame platform at the immediate base of the architectural multiple television tower.

The lights consist of 5-foot-diameter beacons, utilizing 2500-watt short arc mercury lamps in highly polished reflectors. They will revolve in a horizontal plane at one revolution per minute counter-clockwise approximately 180 degrees in a horizontal plane. As they turn to the building, they will be elevated individually to sweep vertically across the television tower.

Colonel Crown, in announcing the project, pointed out, "The Empire State lights should be easily seen in the six states of New York, Connecticut, Pennsylvania, Delaware, Massachusetts and New Jersey.

Plan for the beacons was originally conceived by Industrial Designer Raymond Loewy; engineering and design of their dual movement electronic controls, and supervision of their installation 1902 feet above the street is handled by Federal Sign and Signal Corp., Chicago.



A.I.A. File No. 31

INSTALLATION AT ST. THOMAS MORE R.C. CHURCH
HIGHLAND ROAD AT ROUTE 19, BETHEL TOWNSHIP, PA.

Lighting a Church

LIGHTING OBJECTIVE: To provide adequate illumination and create a pleasant atmosphere in a new church.

GENERAL INFORMATION: This church measures 40 feet by 128 feet. The finished ceiling slopes from 13 feet 9 inches in the center down to 9 feet 2 inches at the sides of the church. Surface characteristics are as follows:

ceiling, pressed fiber glass panels	tan	30% RF
walls, nave		
panels, fabric covered plywood	light tan	30% RF
strips, aluminum	aluminum	75% RF
walls, altar area, scored plywood	cream	50% RF
floor		
nave, asphalt tile	dark green	17% RF
altar area, linoleum	dark green	15% RF
altar area, carpet	red	7% RF
doors, near altar area, oak	blonde	50% RF
altar, oak	blonde	50% RF
pews, oak	blonde	50% RF
chairs, in altar area		
upholstery	dark green	15% RF
wood	light oak	50% RF

INSTALLATION: General lighting is provided by sixteen luminous ceiling panels located as shown in Fig. 2. Each panel is formed by three fluorescent wiring channels (Gotham Lighting Corp.) mounted above corrugated white diffusing plastic (Sylvania Electric Products, Inc.) as detailed in Fig. 3. Each channel uses two 72-inch T-8 200 ma standard cool white slimline fluorescent lamps. Three downlights (Kirlin Co.) are recessed in the canopy over the main altar area. The center downlight (catalog no. 1212) is equipped with a 12¼-inch heat-resisting wide spread lens

(over)

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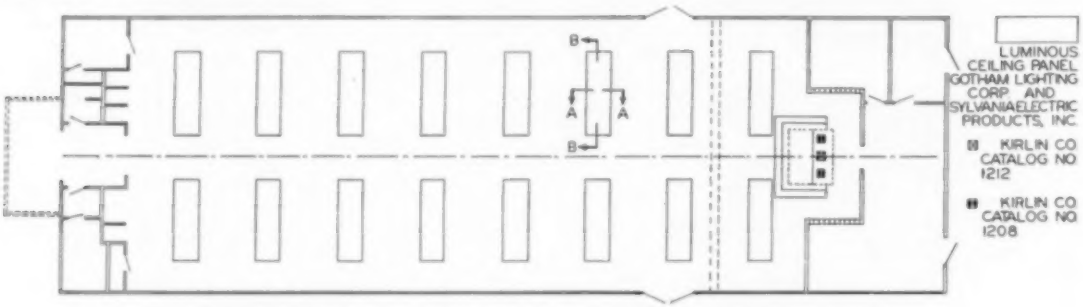

Figure 2. Plan view of church showing location of lighting equipment.

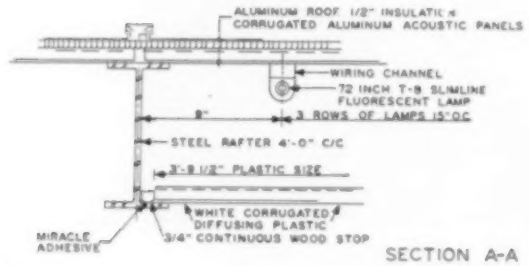

Figure 3. Cross-section A-A through luminous ceiling panel.

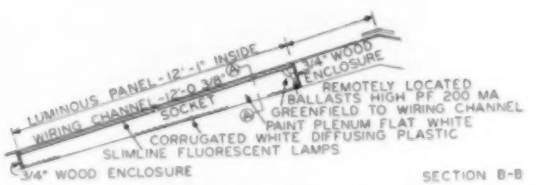

Figure 4. Longitudinal section B-B through luminous ceiling panel.

and a 200-watt PS-30 inside frosted general service lamp. Both of the other downlights (catalog No. 1208) are equipped with heat-resisting wide spread lenses and 150-watt A-23 inside frosted general service lamps.

Illumination at the center of the altar is 40 footcandles and at the edge and steps is 25 footcandles. Average general illumination in the nave 30 inches above the floor is 16 footcandles. Brightnesses are as follows:

luminous panels		walls	
crosswise at 45°	130 ft-L	nave	4.8 ft-L
crosswise at 30°	80 ft-L	behind altar	2.5 ft-L
lengthwise at 30°	120 ft-L	at altar	10 ft-L
canopy downlights, at 30°		side altar	8 ft-L
center downlight	2600 ft-L	floor, altar area	
side downlights	1800 ft-L	linoleum	3 ft-L
ceiling, between luminous panels	2.4 ft-L	carpet	0.7 ft-L
canopy		door, near altar area	5.3 ft-L
ceiling between downlights	4 ft-L	altar rail	7 ft-L
front edge	3.5 ft-L	chairs, in altar area	5 ft-L
		pews, back	2.5 ft-L

Lighting designed by Schell, Deeter and Stott, Architects, Clark Building, Pittsburgh, Pa., and L. T. Knight, Illuminating Engineer, Duquesne Light Co., 435 Sixth Ave., Pittsburgh, Pa. Lighting installed by Frank Haubelt Electric Co., 233 Amada St., Pittsburgh, Pa.

Lighting data submitted by Armand Zitelli, Duquesne Light Co., 435 Sixth Ave., Pittsburgh, Pa., as an illustration of good lighting practice and to aid in the design of similar installations.

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Series XXI 4-56

Measured Utilization Data For Luminous Ceilings

By ANSON H. RUSSELL
RUSSELL D. CHURCHILL

In recent years interest in lighting with luminous ceilings has been growing rapidly because they offered reductions in average ceiling brightness as they were increased in extent up to the room dimensions. The louverall type[1,2] gives a high degree of brightness control in the shielded zone — the translucent panel type offers some control of brightness by diffusion in the direction of work surfaces below. The latter type is the subject of this paper.

Luminous ceilings are composed essentially of a translucent diffuser and its supports, a reflecting cavity and properly disposed light sources. Edwards presented a paper[3] on translucent glass ceilings as early as 1914, and others have contributed over the years to the technology of such luminous elements[4,5,6] although in most cases they dealt with elements of smaller size, less favorable cavity proportions and different materials than those commonly used at present.

The characteristics of many present day translucent ceilings approach the perfect diffusion and uniform brightness which are conveniently assumed for purposes of mathematical analysis. Thus, for example, the work of Yamauti[7] and others may be used to determine utilization for diffusing luminous elements in black rooms. The interflection method of Moon and Spencer[8,9] has been adapted by them to deal with the more complex problems posed by connected reflecting enclosures[10,11] representing the spaces above and below a translucent ceiling in typical rooms. Their basic assumptions include, of course, complete diffusion and initial uniformity of diffuser brightness. Measurements on the enclosure or luminous element, consisting of reflecting cavity and lamps together with the translucent panel, have been reported. For example, Losh[12] measured initial illumination (black room) on walls and floor to determine the fractions of output directed thereto as well as total output. Haskins[13] and Jeavons, Horner and Burnham[14] presented efficiency measurements of such elements. These data deal only with the characteristics of the luminous elements and are applied for actual reflecting rooms with the aid of interflection data.

The authors felt that accurately measured overall utilization data for typical luminous ceilings in complete rooms were needed. Our flexible laboratory facilities,[15] previously used for obtaining utilization data on a variety of luminaire installations, [16,17] were well adapted to this purpose and have been used for a limited number of such tests.

Test Room and Cavity

For the measurement of Coefficients of Utilization,[18] a square room, 12½ feet on each side, with

Figure 1. View of the interior of the 12½ ft x 12½ ft room used for measurements of utilization. Entire luminous ceiling element movable to provide desired range of room proportions. Maximum floor-to-plastic diffuser distance used was 14 feet. Lightcell height (work-plane) adjustable.

A paper presented at the National Technical Conference of the Illuminating Engineering Society, September 12-16, 1955, Cleveland, Ohio. Authors: Application Engineering, Large Lamp Department, General Electric Company, Nela Park, Cleveland, Ohio.

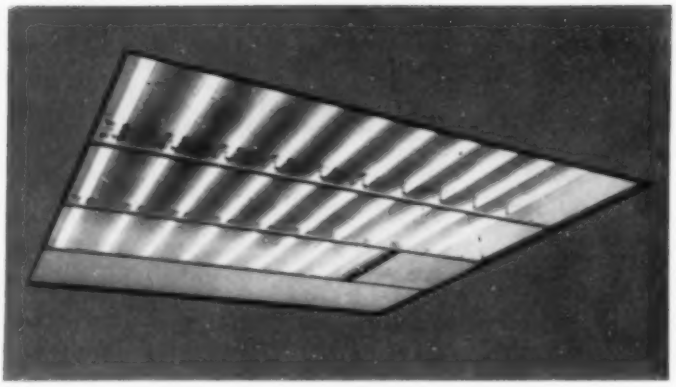

Figure 2. Looking into the luminous ceiling cavity. Shallow cavity (11-inch depth) obtained by inserting pieces of white carton board between channels to simulate a flush mounting condition. Plastic diffuser held in place by aluminum support members two inches wide.

a movable ceiling for changing room proportions was chosen, (Fig. 1). Larger areas represented by this room at reduced scale were measured without sacrifice of accuracy because of the homogeneity of the luminous ceiling source. Wall reflectances[19] used were 0.50, 0.20, and 0.00; for the latter value the walls of the test room were removed allowing the light to escape into a large, black space surrounding the test room. Floor reflectances were 0.30 and 0.10. A lightcell of the turret type with a high degree of cosine and color correction was used in conjunction with an automatic recording device to measure illumination at the work-plane. In rooms of ratio 0.6 (J) through 2.5 (D), the work-plane-to-floor distance was set at one-quarter the luminous element-to-floor distance by adjusting lightcell height with each change in element height.[20] For room ratios 3.0 (C) through 5.0 (A) a constant work-plane height was used to avoid shadowing the lightcell by the searching mechanism. Coefficients of utilization for these larger ratio rooms were adjusted to the one-quarter work-plane-ceiling-height relationship based on data obtained in the previous laboratory test rooms, a sample of which was published in Reference 16.

Above the plastic, cavities of proportions typical of many in actual use were chosen. Cavity surfaces were maintained between 0.84 and 0.85 reflectance. For all utilization tests continuous rows of lamps (ten rows of three 40-watt lamps each) were placed on 15-inch centers, and a lamp-to-plastic distance of 10 inches was used (Fig. 2). Cavity depth for most tests was 13¾ inches (D/W or k_r' of 0.0917) with the lamp channel surface-mounted. A few selected tests were made where the reflecting surface was brought out flush with the channel to eliminate any trapping effect due to the exposed channels. This resulted in a cavity depth of 11 inches (D/W or k_r' of 0.0733). Lamp-to-plastic distance was unchanged. Utilization increased only about one per cent for this slightly shallower cavity. Calculations of cavity efficiency, given in Table I, show about the same difference for Diffuser B.

Plastic Diffusers

A wide variety of diffuser materials and forms is available for practical applications. The choice among them for a particular installation naturally involves considerations of weight, ease of handling and cleaning, rigidity, pattern and texture, cost, safety, and diffusion as well as efficiency of element and overall utilization in the particular room. The authors of necessity selected but three types for the present series of tests. One should not infer that these materials necessarily are of preferred types. Rather, they represent merely certain values of transmittance, reflectance and diffusion. These characteristics[21] are set forth in Table II.

The ceiling pattern consisted in each case of four

TABLE I — Calculated* Cavity Efficiencies and Effective Ceiling Reflectances for Test Room.

Cavity: 12½′ x 12½′ square, reflectance 0.845
Lamps: Spaced on 15″ centers, lamp-to-plastic distance 10″

Diffuser	A	B	C	
Diffuser Transmittance**	0.63	0.53	0.45	
Diffuser Reflectance**	0.28	0.39	0.45	
Cavity Depth†	13.75″	13.75″	11″	13.75″
D/W (or k_r') of Cavity††	0.0917	0.0917	0.0733	0.0917
Fraction to Ceiling†††	0.467	0.467	0.491	0.467
Fraction to Walls†††	0.109	0.109	0.085	0.109
Fraction to Plastic†††	0.424	0.424	0.424	0.424
Cavity efficiency "η"	0.718	0.682	0.688	0.622
Effective ceiling refl. "ρ_e"	0.690	0.717	0.722	0.703

*From finite cavity equations 13a and 16a of Reference 11.
**Measured with Baumgartner Reflectometer; plastic backed with black velvet for reflectance measurements.
†Channel surface mounted for deep cavity; flush mounted for shallow cavity.
††D/W equals depth divided by width for a square cavity.
†††Fraction of lamp output to the inside surface of the cavity without inter-reflection. Estimated from summation of angles from lamps to cavity surfaces as described in the Appendix.

TABLE II — Characteristics of the Selected Diffusers Tested.

Diffuser	A	B	C
Transmittance*	0.63	0.53	0.45
Reflectance*	0.28	0.39	0.45
Flux-Ratio**	0.400	0.389	0.368
Thickness	0.125"	0.125"	0.007"
Corrugation (inches per cycle)	2.5	2.5	1.0
Type of Material	Acrylic	Acrylic	Vinyl

*Measured with Baumgartner Reflectometer; plastic backed with black velvet for reflectance measurements.
**For the complete luminous element (24" square) used for auxiliary tests and described in the text. The procedure for determining the Flux-Ratio for any distribution is given in Reference 17.

continuous panels about 36 inches wide, held in place by aluminum supporting members. One plastic was flexible and used in long rolls; the others were in stiff sheets about a yard square and were overlapped one corrugation.

Auxiliary tests to determine relative efficiencies and candlepower distributions were made with a conventional polar photometer,[22] using each of the three plastics as the diffuser for a small luminous element 24 inches square. This test element or box had a relatively deep cavity (10½ inches); its D/W or k_r' ratio was 0.438 as compared with the value of 0.0917 for the relatively shallow cavity used for the test room. A single 20-watt T-12 fluorescent lamp was placed 8½ inches from the plastic with corrugations oriented both parallel and at right angles to the lamp. The cavity (box) reflectance was the same as that used in the cavity of the test room (0.845). Measured efficiencies are compared in Table III, on a relative basis, with calculated values based on the exact box conditions. They agree well. Candlepower distributions, averaged for three planes are compared in Fig. 3. One material (Diffuser A) was a little less diffusing, and thus its distributions taken crosswise and lengthwise the corrugations were slightly different. Values of a recently proposed index of concentration or Flux-Ratio[17, 23] are included in the caption of Fig. 3 and in Table II.

TABLE III — Comparison of Measured and Calculated Efficiencies* of a Small Luminous Element.

Lamp: Single 20-watt T-12 lamp, lamp-to-plastic distance 8½"
Box: 24" x 24" square, 10½" deep, reflectance 0.845

Diffuser	A	B	C
Measured Value	1.00	1.00	1.00
Calculated Value**	1.00	1.02	0.98

*Relative efficiencies based on measured value as unity; values should not be compared as between different plastic diffusers.
**Fractions of light output initially incident on box surfaces were estimated as described in the Appendix. Calculations were based on equation 16a from Reference 11.

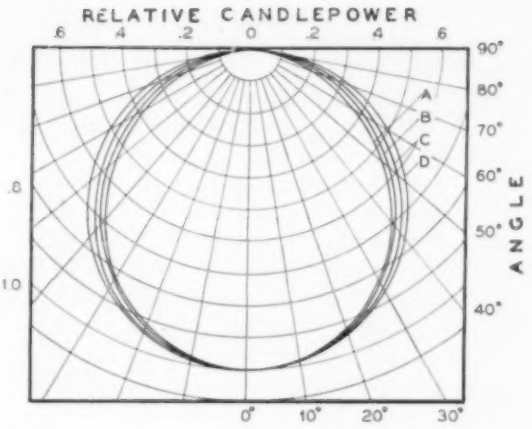

Figure 3. Candlepower distribution curves from three plastic diffusers compared to theoretical cosine curve. A model element 24 inches square and 10½ inches deep, with plastic diffusers covering the opening one at a time, was photometered at 18½ feet.

Curve	Plastic Diffuser	Flux Ratio[17]
A	Diffuser A	0.400
B	Diffuser B	0.389
C	Diffuser C	0.368
D	Theoretical cosine	0.353

Calibration and Testing

All the precautions in calibrating and testing previously exercised in our laboratory were followed in the present measurements. The operating temperature of the fluorescent lamps in the cavity was one of the more important considerations because of its significant effect on lamp output. Accordingly, the outputs of thirty carefully selected 40-watt T-12 standard warm white lamps, used in the tests, were determined at a bulb wall temperature of 108 degrees Fahrenheit. Then, curves of lamp output versus bulb wall temperature were derived for each of three lamps operating under its particular ballast condition. These curves were later applied to correct lamp output from the 108-degree value to their actual outputs at the temperatures read during each test. A thermocouple on each of the three above mentioned lamps was used for this purpose. Lamps were allowed to heat for one-half hour before measurements of utilization were begun.

Data for Application

For predetermining average illumination at the work-plane in any luminous ceiling installation, accurate and easily applicable design data are needed. For this purpose the authors present a

TABLE IV A — Coefficients of Utilization for Luminous Ceilings.

DIFFUSER			DIFFUSER A			DIFFUSER B			DIFFUSER C		
Cavity Reflectance			0.85			0.85			0.85		
Wall Reflectance			0.50	0.30	0.10	0.50	0.30	0.10	0.50	0.30	0.10
	Room Ratio*										
	0.6	(J)	.288	.226	.190	.266	.215	.180	.232	.188	.160
	0.8	(I)	.362	.297	.257	.332	.283	.247	.286	.242	.216
	1.0	(H)	.416	.355	.312	.380	.335	.298	.333	.290	.264
	1.25	(G)	.467	.406	.367	.426	.382	.345	.380	.337	.313
Floor	1.5	(F)	.504	.445	.410	.461	.418	.380	.419	.375	.350
Reflectance	2.0	(E)	.555	.501	.471	.511	.470	.434	.476	.430	.403
0.10	2.5	(D)	.589	.540	.513	.548	.510	.475	.513	.466	.440
	3.0	(C)	.614	.569	.544	.575	.538	.504	.539	.494	.467
	4.0	(B)	.647	.609	.585	.612	.576	.543	.573	.529	.502
	5.0	(A)	.668	.631	.609	.638	.601	.570	.594	.550	524
	0.6	(J)	.296	.235	.191	.284	.223	.183	.235	.195	.162
	0.8	(I)	.375	.305	.258	.360	.289	.245	.294	.251	.220
	1.0	(H)	.439	.364	.315	.418	.343	.297	.345	.300	.269
Floor	1.25	(G)	.500	.426	.375	.476	.400	.353	.399	.355	.321
Reflectance	1.5	(F)	.549	.476	.425	.521	.447	.400	.445	.400	.365
0.30	2.0	(E)	.611	.548	.500	.577	.512	.469	.510	.466	.430
	2.5	(D)	.649	.590	.549	.614	.553	.514	.545	.508	.476
	3.0	(C)	.676	.620	.582	.641	.584	.548	.570	.536	.509
	4.0	(B)	.712	.660	.625	.679	.625	.594	.603	.576	.550
	5.0	(A)	.740	.689	.656	.706	.651	.626	.625	.600	.575

Table based on measurements in 12½′ square rooms; work-plane height equal to ¼ ceiling height above the floor; cavity depth 13¾"; lamps spaced on 15" centers; lamp-to-plastic distance 10".

*Room Ratio $= \dfrac{W \times L}{MH_{wp}\,(W + L)}$; where MH_{wp} = distance from plastic diffuser to work-plane.

practical table of Coefficients of Utilization which includes a number of the conditions encountered in practice (Table IV A and B). For each of three diffusers tested, a variety of reflectance combinations and room proportions are covered. The two cavity reflectances selected are in the range of typical white paints available today, and the room wall and floor reflectance values are those recommended by the IES Lighting Design Practice Committee. Any depreciation of cavity or room surface reflectance should, of course, be accounted for in the assigned maintenance factor; this is in accord with current practice.[24] Although the coefficients of utilization are based on but one cavity proportion (D/W or k_r'), it represents a practical shape, and small deviations from it should introduce relatively little error. However, relatively deep cavities, sometimes found above luminous ceilings, cause a significant decrease in efficiency and utilization. If desired, a correction for any cavity proportions can be derived with the aid of calculations.

The values in Table IV A, for cavity reflectance of 0.85, were derived directly from measurements

TABLE IV B — Coefficients of Utilization for Luminous Ceilings.

DIFFUSER			DIFFUSER A			DIFFUSER B			DIFFUSER C		
Cavity Reflectance			0.75			0.75			0.75		
Wall Reflectance			0.50	0.30	0.10	0.50	0.30	0.10	0.50	0.30	0.10
	Room Ratio*										
	0.6	(J)	.255	.200	.168	.230	.186	.155	.199	.161	.137
	0.8	(I)	.321	.263	.228	.287	.244	.213	.245	.207	.185
	1.0	(H)	.369	.315	.276	.328	.289	.257	.285	.248	.226
	1.25	(G)	.414	.360	.325	.368	.330	.298	.325	.288	.268
Floor	1.5	(F)	.447	.394	.363	.398	.361	.328	.359	.321	.300
Reflectance	2.0	(E)	.492	.444	.417	.441	.406	.375	.407	.368	.345
0.10	2.5	(D)	.522	.478	.455	.473	.440	.410	.439	.399	.377
	3.0	(C)	.544	.504	.482	.496	.464	.435	.461	.423	.400
	4.0	(B)	.573	.540	.518	.528	.497	.469	.490	.453	.430
	5.0	(A)	.592	.559	.540	.551	.519	.492	.508	.471	.449
	0.6	(J)	.262	.208	.169	.245	.192	.158	.201	.167	.139
	0.8	(I)	.332	.270	.229	.311	.249	.211	.252	.215	.188
	1.0	(H)	.389	.323	.279	.361	.296	.256	.295	.257	.230
Floor	1.25	(G)	.443	.377	.332	.411	.345	.305	.342	.304	.275
Reflectance	1.5	(F)	.486	.422	.377	.450	.386	.345	.381	.342	.312
0.30	2.0	(E)	.541	.486	.443	.498	.442	.405	.437	.399	.368
	2.5	(D)	.575	.523	.486	.530	.477	.444	.467	.435	.407
	3.0	(C)	.599	.549	.516	.553	.504	.473	.488	.459	.436
	4.0	(B)	.631	.585	.554	.586	.539	.513	.516	.493	471
	5.0	(A)	.656	.610	.581	.609	.562	.535	.535	.514	.492

Coefficients for Table IV B derived by applying calculated adjustment ratios to the measured values in Table IV A.

*Room Ratio $= \dfrac{W \times L}{MH_{wp}\,(W + L)}$; where MH_{wp} = distance from plastic diffuser to work-plane.

in the test rooms. Table IV B, for cavity reflectance of 0.75, was constructed using Table IV A as a base and deriving from calculations the necessary downward correction for each plastic diffuser. The adjustment included corrections of cavity efficiency, and room utilization due to the change in effective ceiling reflectance.

Two important factors which should be considered in applying these tables are the physical obstructions in the cavity, including diffuser supporting structure, and the ambient temperature in the cavity. In view of the fact that actual installations vary widely in these respects, no attempt has been made to include the range of these variables in the tables. They are based on minimum practical cavity obstruction and on the normal temperature rating of fluorescent lamps (80°F ambient).

For cavities where ducts, pipes and prominent beams are present, lower utilizations would be expected. In such cases high reflectance white paint should be applied to all such obstructions as well as to the walls and soffit of the cavity. In our test rooms the cavity included obstruction only from lamps and channels and from two-inch wide diffuser supporting members spaced approximately three feet apart. The latter obstruction represents about six percent of the ceiling area.

As to temperature, air conditioning of the cavity should keep the ambient within the range of efficient fluorescent lamp operation. Without some means of temperature control, the cavity ambient may vary widely with the season, the thermal characteristics of the element, and the length of time the lamps are in continuous operation. To aid in estimating the correction applied to rated lamp output values for various ambient temperatures in the cavity, Fig. 4 is presented. The data on which this curve is based were taken from the Forbes-Diefenthaler study[25] of the effects of temperature and other factors on fluorescent lamp operation. Throughout our measurements of utilization from which Table IV was compiled, temperature corrections of from 0 to 13 per cent were made to keep the coefficient values on a rated lamp output basis. Thus, it appears that under extreme conditions, the downward adjustments for cavity ambient temperature and physical obstructions may for some installations approach 20-25 per cent.

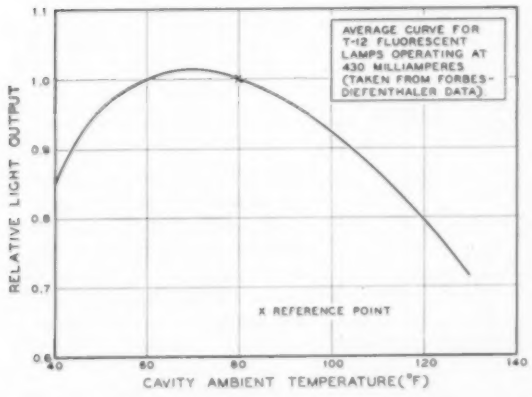

Figure 4. Curve relating fluorescent lamp output to ambient temperature in the cavity. Included for convenience in estimating a correction factor to be applied to rated lamp output when lamps operate under temperature conditions different from their normal temperature rating. Curve derived from Forbes-Diefenthaler data, Reference 25.

Measurements and Calculations Compared

Luminous ceiling installations comprise a variety of diffusing media covering a wide range of reflectance and transmittance values, numerous cavity proportions, and various cavity surface reflectances. It would, of course, be impracticable to attempt measurements of utilization for the multitude of combinations of these variables. Therefore, it was felt that accurate correction factors might readily be derived by calculation and employed to expand the basic measured data of Table IV A for other desirable cavity conditions. This was done, for example, in Table IV B for a cavity reflectance of 0.75. Also calculated coefficients of utilization provide a convenient comparison with measured values inasmuch as luminous ceiling lighting conditions closely approximate the assumptions of perfect diffusion and uniform brightness distribution on which the interflection[8] equations are based. A previous study[26] by one of the authors also indicates that a reasonable correlation may be expected.

Calculated coefficients were derived from the product of room utilization and cavity efficiency. The conditions for which the latter was calculated are presented in Table I, and are identical with the conditions of the finite test room cavities. Calculated effective ceiling reflectances are also included for use in computing room utilization.

Selected values of measured utilization data, typical of the many actually measured, are compared with calculated values in Table V. This selection includes the three types of plastic diffusers tested, and a variety of room proportions and room surface reflectances representative of the range of conditions tested. Differences range from −17.9 per cent in a 0.6 (J) room to +5.9 per cent in a 5.0 (A) room. To show the trend of such comparisons over the standard range of room ratios, two sets of curves, each for a different reflectance

TABLE V — Measured and Calculated Coefficients of Utilization.

Cavity: 12½′ x 12½′ square, 13¾″ deep, reflectance 0.845
Lamps: Spaced on 15″ centers, lamp-to-plastic distance 10″
Channel: Surface mounted

DIFFUSER	A		B				C	
Room Ratio**	0.6(J)	2.5(D)	0.6(J)	1.25(G)	2.5(D)	5.0(A)	1.25(G)	5.0(A)
"k_r" of Room	1.111	0.267	1.111	0.533	0.267	0.133*	0.533	0.133*
Wall Reflectance	0.50	0.50	0.30	0.50	0.50	0.10	0.30	0.50
Floor Reflectance	0.30	0.30	0.30	0.30	0.10	0.10	0.10	0.30
"f" (Ceiling Lighting)†	0.355	0.907	0.268	0.673	0.835	0.869	0.546	1.063
Calculated C.U.	0.255	0.651	0.183	0.459	0.569	0.592	0.340	0.662
Measured C.U.	0.296	0.649	0.223	0.476	0.548	0.570	0.337	0.625
Diff. in Per Cent††	−13.9	+0.3	−17.9	−3.6	+3.8	+3.9	+0.9	+5.9

*k_r computed for $h'/h = 0.75$, since measurements were corrected to this condition.
**Harrison-Anderson direct room ratio.
†From published table cross-plotted for k_r and ρ_{fl} values desired (Table XIV of Reference 8).
††Difference between measured and calculated coefficients in per cent of the former.

combination, are presented in Fig. 5. The calculated coefficients range from approximately 0.85 of the measured value in a 0.6 (J) room to 1.03 in a 5.0 (A) room.

Certain minimum cavity obstructions which trap light, such as lamps, channels and supporting members are necessary for practical construction of luminous ceilings and affect the results for the test room if only in minor degree. But coefficients calculated from the equations are relatively high without allowance for this factor. This is apparent in Fig. 5 for rooms with high room ratio (larger rooms) where other differences are minimized.

Three factors which tend to make calculated coefficients of utilization lower than corresponding measured values are: (1) the conservativeness in the basic calculation concept for rooms of low room ratio (high, narrow rooms), (2) the assumed uniformity of initial brightness of the diffuser extending all the way to the room perimeter, and (3) the assumption of cosine candlepower distribution from the diffusing element as compared to the slightly more concentrating distributions actually tested (Fig. 3). These have their greatest effect in tall-narrow rooms where they overcome the tendency toward higher calculated values due to lack of obstructions previously mentioned (see Fig. 5).

Explorations using Flux-Ratio charts similar to those in Reference 17 indicate that the differences in utilization due to variations between distributions A and D (cosine) in Fig. 3 (Flux Ratios 0.400 and 0.353) would be at least 7 to 11 per cent in 0.6 (J) rooms. On the other hand, in rooms of ratio 5.0 (A) the effect of flux distribution was found to be only two per cent.

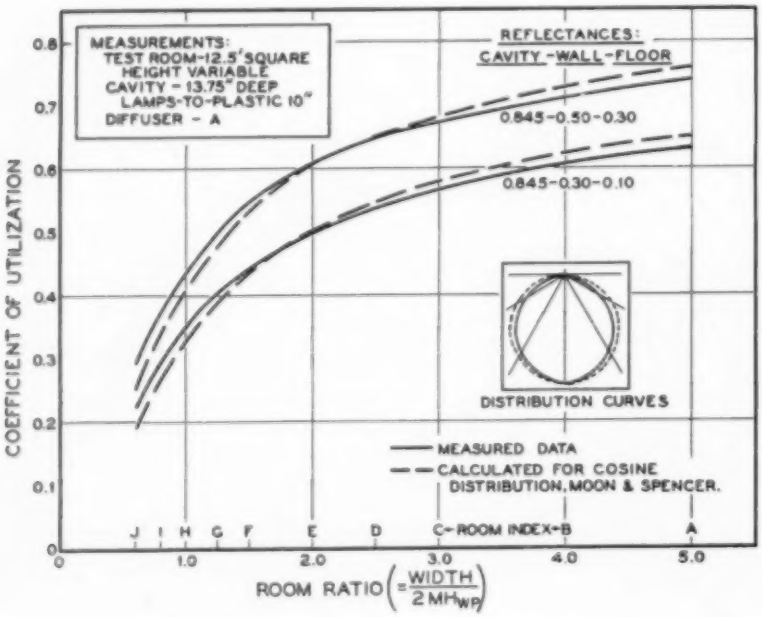

Figure 5. Specimen curves of measured and calculated coefficients of utilization, for Diffuser A at two reflectance combinations. Calculated values include no corrections for cavity or panel obstructions.

Summary

For luminous ceilings, coefficients of utilization derived directly from measurements are presented ready for use. However, it is pointed out that caution should be exercised in the cases where lamps are operated at temperatures different from their normal rating, and where obstruction by elements foreign to the lighting equipment are present. In both cases, generally, the utilization will be reduced and allowances should be introduced.

Test results indicate that coefficients of utilization calculated from equations for cavity efficiency and room utilization are slightly optimistic in rooms of higher ratios, and conservative in high, narrow rooms. In the first case calculations without allowance for obstructions account for the difference; in the latter, the approximations in the basic calculation method and the assumptions of uniform initial brightness and a perfect cosine distribution are the principal factors.

The authors acknowledge gratefully the counsel and guidance of their colleagues, Messrs. C. M. Cutler and W. M. Potter.

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18. Footnote: Coefficient of Utilization as used in this publication is the total luminous flux to the work-plane divided by the total output of the bare lamps. It is equal to the room Utilization Factor times the cavity Efficiency.
19. Footnote: Measurements of reflectance were made with a Baumgartner Reflectometer; beam of light directed onto sample at 30 degrees from the normal, reflected light integrated in a sphere.
20. Footnote: This fraction may vary, but one-quarter is representative of numerous installations.
21. Footnote: Measurements of reflectance and transmittance of plastics were made with a Baumgartner Reflectometer. For reflectance, a beam of light was directed onto plastic sample, backed with black velvet, at 30 degrees from the normal, reflected light integrated in a sphere. For transmittance, diffused light from a sphere below the sample was transmitted by plastic and measured from above with the reflectometer sphere.
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APPENDIX

In order to employ the equations[11] for determining cavity efficiency and effective ceiling reflectance for finite cavity conditions, it was necessary to first determine the fractions of lamp output initially incident on the cavity surfaces. Accordingly, a simple method of estimating these fractions for rows of fluorescent lamps, suggested by W. M. Potter, was employed. Angles from the sources to the cavity surfaces were measured on a cross-section view of the cavity looking into the ends of the rows of lamps. These angles were then assumed to be proportional to the fraction of lamp output to the respective cavity surfaces.

For example, the 24-inch square box with a single fluorescent lamp used for relative efficiency measurements (Fig. 6), would result in the following estimated fractions:

Surface	Angle	Fraction
Top of box	A	0.448
Sides of box	B+B′	0.247
Plastic diffuser	C	0.305

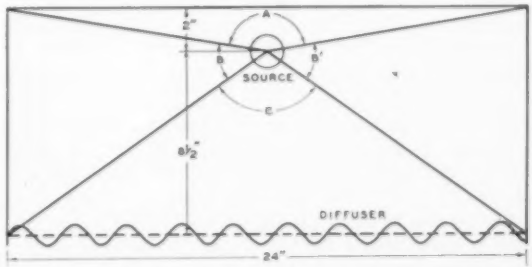

Figure 6. Illustrating method used to estimate the fraction of lamp output initially incident on inside surfaces of 24-inch square box for calculations of relative efficiency (Table III). A similar technique was employed to estimate fractions to surface inside the test room luminous ceiling cavity to aid in calculations of cavity efficiency and effective ceiling reflectance (Table I).

This method does not account for interference from lamps (or channels in the case of the test room cavity) or light to the end walls of the cavity. However, the resulting error should be small. Obstructions are at a minimum, and most fluorescent lamps put relatively little light on the end walls. Furthermore, it was found that differences in cavity efficiency and effective ceiling reflectance between the finite cavity equation and the infinite equation, where no light to the sides of the cavity is assumed, were less than eight per cent for a cavity of the proportions used in our test room. Therefore, the method suggested should give fairly accurate estimates of light incident to cavity surfaces for use with the finite equations.

This method of estimating was previously used to advantage in analyzing the effect of lamp position on light passing between parallel louver blades.

DISCUSSION

RUSSELL C. PUTNAM:* It is with a special interest that I have read this paper as it was only a few years ago that the authors were students in classes in illuminating engineering taught by this discussor. This is one of those situations which always delight any teacher, when former students add to the total of knowledge in a technical field and do it as well as in this case. This paper presents much valuable data for luminous ceiling computation, logically presented and analyzed.

In the wide coverage of the subject the authors point out two factors of which the effect can only be estimated; the physical obstructions in the cavity and the ambient temperature of the cavity. Now that the luminous ceiling structure is beginning to be used in some cases as part of the ventilation or air-conditioning systems, the effect of the ambient temperature of the cavity is important because of is effect on fluorescent lamp operation. There is certainly a need for definite information and methods of computation in order that the ambient temperature of the cavity can be predetermined with accuracy. This will involve the joint efforts of heating, ventilation, and air-conditioning engineers working with illuminating engineers. Such cooperation has been shown before in a paper in ILLUMINATING ENGINEERING, involving another problem concerning luminous ceilings[1] and it is to be hoped that in this most important cavity ambient temperature problem we may also be able to stimulate interest and enlist the help from our friends in the ventilation and air-conditioning fields.

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GERALD MARKS:** There are some people in the lighting industry who think that the luminous ceiling is the answer to all lighting problems. However, as the authors point out, in the application of luminous ceilings there are a few additional questions which still have no answers.

The authors ask that heating and ventilating engineers give us more information concerning the problem of cavity temperatures so that more accurate prediction of coefficients of utilization can be had. However, let us not forget that we should give more accurate information to them so that they can do a more accurate job of cooling and heating. It could be a vicious circle, but the data presented in this paper should be considered a big step in the elimination of these problems.

It should be pointed out that two of the problems that are important in luminous ceiling design are also factors in the design of any lighting system. It is true that the question of cavity obstruction and ambient temperatures may have a greater effect on luminous ceiling design than on lighting system design, but the fact remains that little is known about the effect of these two factors on lighting system design. Perhaps this should be phrased that very seldom are these two factors considered in any lighting system, much less luminous ceiling.

Getting the answers to the problem of cavity obstructions and more accurate information about ambient temperatures in a room will not only aid the designer of luminous ceilings, but also the designer of any lighting system.

GEORGE W. CLARK:* We continue to get very excellent and highly valuable data from the laboratory facilities with which the authors of this paper are working. The report we have just heard is particularly significant both as to results and subject.

Having as early as 1949 introduced a modular wall-to-wall lighting system using the vinyl plastic diffusers, we have been more than ordinarily aware and concerned with the inadequacy of the illumination design data generally offered by both the *I.E.S. Lighting Handbook* and the individual manufacturers. This situation has led to a general practice of using a ridiculous safety factor which is neither flattering to us as illumination engineers nor fair to the customer we serve. With the introduction of still another wall-to-wall system about a year and a half ago, we were determined to attempt to do a better job of providing design data. Almost without exception the data then available were based on the assumption of a cavity of a single arbitrarily assumed efficiency. Our experience convinced us that the cavity variations were often more significant than the variations in the room to be lighted. While many of the calculation methods appeared to be based on the paper "Interflections in Coupled Enclosures" by Moon and Spencer which appeared in the August 1950 issue of the *Journal of the Franklin Institute*, they likewise seem to have used the most simplified versions of the equations offered in this work. Unfortunately, the assumptions made to arrive at this simplification do not correspond with practice.

At the risk of appearing to overcomplicate matters, we decided to revert to the exponential form of the basic design equations offered by Moon and Spencer in their "Coupled Enclosures" paper. These offered the opportunity to take into consideration nearly all the important cavity variations except for obstruction which unfortunately must be accounted for in a manner similar to our luminaire maintenance factors. Our first attempt at reducing these equations was provided our field engineering force about a year ago and consisted of a not unreasonable combination of graphs and tables in a six-step procedure. To provide a more compact version for publication in semi-technical literature, one of my colleagues has more recently devised a format for a coefficient of utilization table which still recognizes the major variations in the cavity. Before he explains this and the correlation with the measured data shown by Messrs. Russell and Churchill, I should like to make one final point which seems to have been overlooked in most attempts to provide data for wall-to-wall lighting systems.

If we accept the work of Moon and Spencer on coupled enclosures, we must give consideration to the specific type of luminaire used. Both the distribution characteristics and the efficiency must be considered since both are sig-

*Case Institute of Technology, Cleveland, Ohio.
**Electro Silv-A-King, Chicago, Ill.

*Manager, Engineering, Sylvania Electric Products Inc., Wheeling, West Va.

nificant in determining the cavity efficiency. There is obviously a difference in both these elements between a conventional "strip" unit and a "ladder" or "grid" arrangement of lamps and channels.

The conclusion we have drawn from this is that each manufacturer or designer of such lighting systems must develop data based on the specific equipment involved (including plastic and luminaires) and for a variety of cavity proportions and reflectances.

MAXWELL L. TROSTLE:* I want to take this opportunity to congratulate the authors on their accomplishment. Their effort has been tremendous, and their published work has great value to all of us. Let us hope to hear more along this same line from these authors or others among us. The paper, however, does impose certain restrictions and limitations.

As Mr. Clark has pointed out, we decided about a year and a half ago that a simple and workable method be devised which would be used for the calculation of illumination for wall-to-wall lighting systems. My job became that of developing a set of coefficients of utilization tables which had none of the limitations of those available. The Moon and Spencer equations were selected as the basis for this work.

In order to determine the coefficient of utilization, it is necessary that the cavity efficiency and the interflectance factor of the room be known. I had, then, to calculate the cavity efficiencies and the apparent reflectance figure used in locating the applicable interflectance factor.

Values of cavity efficiencies for cavity surface reflectances of 85, 75, 50 and 10 per cent with room shape factors for the cavity going from 0 to 1.0 in increments of 0.1 were calculated. This broader range of reflectances is felt necessary since the cavity is not always given a good white finish even though that should be done where possible. Similarly, a series of calculations were made in order to determine the apparent ceiling reflectances over the same range. From these calculations sets of curves were drawn which, together with published "*f*" tables, permit the determination of the coefficient of utilization over a far broader range than is possible with other generally available data.

As a further development, two coefficients tables, for cavity reflectances of 85 and 75 per cent, were built up from the curves and other data. Since the cavity shape factor is of considerable importance, it became necessary to include that factor in the tables. It can be shown quite easily, by the way, that small deviations in cavity depth can account for errors of the order of 2 per cent. On the practical basis, the cavity depth may be considerably in excess of the 13¾ inches used by the authors of the paper in the derivation of their tables.

While the tables (see drawing) are based, as are those of the authors, on a work plane height equal to ¼ the distance from the floor to the diffuser, it has been determined that the maximum deviation in the coefficients for rooms of from 8 feet to 16 feet (floor to diffuser) is in the order of 3 per cent. It should be pointed out as well that calculations are based on the use of single-lamp equipment without reflectors having an efficiency of 90 per cent with a relative distribution of 18/72. Other limitations are as given in the paper.

It is my pleasure to have a chance such as this to compare my calculated coefficients with those determined from laboratory measurements. I have found, for instance, that my calculated value for a room comparable to the "J" room of the paper which has floor and wall

	ROOM RATIO OF CAVITY												
	0		0.1		0.2		0.3		0.4		0.5		C
	WALL REFLECTANCE PERCENT												
ROOM RATIO	50	30	50	30	50	30	50	30	50	30	50	30	50
0													
0.1													
0.2													
0.3													
0.4													
0.5													
0.6													
0.7													

reflectances of 10 and 30 per cent, respectively, differs by −2 per cent from the measured coefficient. In the "D" room for 30 per cent floors and 50 per cent walls the percentage difference is +10.8.

The diffuser used for the tables I have calculated is one which approaches in characteristics the diffuser "C" of the paper. The differences in diffusers bring about a difference in coefficients of utilization in the order of 4 per cent, *i.e.*, the diffuser used in the calculations provides coefficients 4 per cent higher than those of the paper.

DOMINA EBERLE SPENCER:* This paper is a valuable contribution in the tradition of Mr. Churchill's excellent Master's thesis on the same subject.

The frequent references to the effect of obstructions on the logance *g* of luminous ceilings are good. Both theoretical and experimental work in this field would be welcome additions to our knowledge of the design characteristics of luminous ceilings.

The graph of the lumen output of the fluorescent lamps versus ambient temperature of the cavity enables one to evaluate quantitatively a factor which has ordinarily been ignored. The only other measurements on the temperature of luminous ceilings that I am familiar with[1] indicated that the air temperature above the diffusing plastic was only about one degree F above that in the room below. This appeared to be a much smaller temperature differential than is ordinarily associated with fluorescent fixtures and was thought to be associated with the relatively high maintenance factors which have been measured for luminous ceilings.[1]

I would like to ask the authors whether, on the basis of their experimental data, one would be justified in saying that the lumen output of fluorescent lamps is somewhat larger when operated in relatively cool luminous ceilings than in fixtures where overheating may take place? Also in those cases in which air introduced into the room through the luminous ceiling, would it insure optimum operation of the lamps by keeping the ambient temperature above the diffusing plastic close to the optimum value of 70 F? Have any measurements been made on the temperature difference between the air near the lamps and near the diffusing plastic?

A criticism which should be directed, I think, not at the authors of this paper but at the general plan of the series of papers to which it belongs concerns the peculiar room ratio used here. It is, of course, an advantage to have the coefficient of utilization tables specified primarily in terms of a numerical specification of room shape and to see the letter indices reduced to a supple-

*Sylvania Electric Products, Inc., Wheeling, West Va.

*University of Connecticut, Storrs, Conn.

mentary position in parentheses. But why introduce a definition of "room ratio" which is defined in terms of the non-fundamental variable — the distance from luminous ceiling to desk top. The distribution of the light in the room is expressed in terms of the height, width and length of a rectangular room, or better yet as a ratio of wall area to floor area

$$k_r = \frac{S_1}{4S}$$

where k_r = domance of room,
S_1 = wall area,
S = floor area.

As the interflection tables (to which this series of papers is closely related) are expressed in terms of k_r, it would be preferable to use a single numerical specification of room shape. For the special case of rectangular rooms and luminous ceilings,

$$k_r = \frac{2}{3} \frac{1}{\text{Room Ratio}}$$

k_r	Letter	Room Ratio
0.133	A	5.0
0.167	B	4.0
0.222	C	3.0
0.266	D	2.5
0.333	E	2.0
0.444	F	1.5
0.533	G	1.25
0.666	H	1.00
0.833	I	0.8
1.11	J	0.6

Use of k_r is even more compatible with the letter indices than room ratio, for the former increases as we move through the alphabet while room ratio runs counter to the sequence.

Another question I should like to ask the authors has to do with the measurements of reflectance and transmittance on the Baumgartner Reflectometer. Have these been checked against values obtained from the General Electric Spectrophotometer and are they measured for the color of the light actually employed in the room? It has been my experience that measurements made on these two instruments are not always in agreement. This discrepancy may decrease the accuracy of measurements.

Nevertheless, the agreement between experiment and predictions of the interflection equations is gratifying, particularly as a sequel to the 30 per cent errors which Dr. Wiseman felt were indicated in his Conference Paper last year. As I pointed out in my discussion of Dr. Wiseman's paper, the difficulties of making photometric measurements are greater than any one experimenter is willing to admit, and the accuracy of any one experiment is generally lower than that estimated by the experimenter himself. In this excellent experiment of Russell and Churchill, a verification of the equation[2] for the logance of the luminous ceiling checks to within ±2 per cent as shown in Table III. Data given in Table V indicate that for the most diffusing of the plastics — the vinyl "C" — errors are less than 6 per cent. Even for the overly transparent acrylics "A" and "B" no discrepancies greater than 4 per cent are shown in examples covering the range $k_r \leq 1$. Even for very high and narrow rooms, and plastics which are more transparent than are really suitable for luminous ceilings the discrepancies are small compared to those claimed by Dr. Wiseman last year.

Fortunately — for the simplicity of lighting calculations — the last year has seen a marked trend toward the more diffusing vinyl rather than the transparent acrylics* which have been used somewhat in the past. Though this trend is primarily dictated by cost differential and by the flame resistant qualities of the plastic, it seems likely that the assumption of a perfectly diffusing surface will be closely approximated by the majority of luminous ceilings. These latest experiments lend strong support to the estimate which Professor Moon and I made before any of the recent experimental checks had been made: that predictions of the interflection method could be expected to be accurate within 10 per cent for recommended reflectances and for rooms ranging from cubical to infinitely large.

As the interflection equations are well known to contain no assumptions save that of perfectly diffusing, uniform floor and ceiling for $k_r = 0$ (very large rooms), I would interpret the slightly low experimental values in this region differently from the authors. I suspect that the cell having a "high degree of cosine and color correction" is reading low when a large fraction of the incident light reaches the cell at a large angle of incidence, that the scanning equipment has become a significant obstruction in very shallow rooms, and that the correction factor used to adjust the coefficients of rooms A, B, and C to ¼ h is not entirely satisfactory. For very small rooms measured values tend to exceed calculated values. This effect is particularly noticeable with the imperfectly diffusing acrylics and is probably associated with the fact that the ceiling is brighter than calculations would predict at small angles of incidence. The data presented in the paper do not indicate that such a changeover occurs for vinyl. Comparison of data from Tables IV-A and IV-B with values calculated for standard recommended conditions and Marlux ceilings fail to indicate a crossover if the shape of the space above the diffusing plastic is kept constant.

Thus, I would interpret these experimental results as another satisfactory verification of the interflection method. However, I think there is no indication that measured values are any more accurate than calculated values or that Table IV has any merit over a similar table computed directly from basic interflection data.

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2. Moon, Parry and Spencer, D. E.: "Interflections in Coupled Enclosures," *Journal of the Franklin Institute*, Vol. 250 (August 1950).

A. H. RUSSELL and R. D. CHURCHILL:** The authors take this opportunity to thank each of the discussors for the interest they have shown in our presentation of practical design data for luminous ceilings.

It is indeed gratifying to receive praise from our former college professor and teacher. Professor Putnam also stresses the need for more information on cavity ambient temperature and physical obstructions. As he points out, obtaining definite information will involve the joint efforts of heating, ventilating, and air conditioning engineers. Mr. Marks has also expressed interest in the desirability of more complete information on cavity ambient temperature and physical obstructions, from the standpoint that it might even be helpful to designers of other types of lighting systems. We feel that with the growing

*Note that acrylics need not be more transparent than vinyl. A wide range of formulations are available in both materials. However, in commercial applications better diffusion has ordinarily been obtained from the vinyls chosen than from the acrylics chosen. A different set of choices could reverse the situation.
**Authors.

trend toward luminous ceiling lighting, the larger investment involved in an installation, and the interest of persons even outside the luminous ceiling field, these factors of cavity ambient temperature and physical obstructions merit a full scale investigation. This could perhaps be done under the supervision or sponsorship of an IES committee, or a subcommittee group composed of engineers from the various fields involved.

In his general discussion of wall-to-wall lighting systems, Mr. Clark's comment on an obvious difference between conventional "strip" units and the "ladder" or "grid" arrangement of lamps and channels is well considered. We are aware of this difference, but question whether the end result (coefficient of utilization) would be affected sufficiently to justify measurements both ways. We feel that in most cases the channels would be very nearly the same reflectance as the white ceiling background, resulting in roughly the same coefficient, except for a small amount of light trapped between each lamp and its channel in the case of "strip" type units.

One finding which Mr. Trostle made relevant to the material presented in our paper is that his calculations of coefficients of utilization confirm our measured data. Obviously this is to be expected since the interflection equations should be most nearly accurate for luminous ceilings, because the assumptions on which they are based come closest to the practical conditions of actual installations. Mr. Trostle also (at the Conference) took this opportunity to present a format illustrating how he expected to present data which seems to take on the aspects of a complete paper. However, it is always a worthwhile endeavor to find a way of presenting complicated masses of data in a simplified organized form.

We have endeavored to place in the hands of the lighting designer a table of coefficients of utilization, presented in an easy-to-use form, taking into consideration the significant variables and practical conditions which he will most likely encounter. Mr. Trostle's format calls for a wide range of cavity proportions. In our experience cavity proportions, even in small rooms such as private offices, are approximately ten times as wide as they are deep. When considering larger rooms, this ratio is increased even further. In this practical range of cavity proportions, cavity efficiency and the resultant coefficient of utilization change very slowly with changes in cavity proportions.

Dr. Spencer appears to be concerned about the subject of temperature in luminous ceilings as compared to lighting fixtures. We have emphasized the fact that our paper was intended to make available lighting design data for a presently popular lighting technique, not to recommend one type of lighting over another. Some luminaires occasion little loss of light due to heat, others considerable. Similarly different conditions of loading, air conditioning and efficiency of luminous ceilings will occasion variations in their output. For example, where there is no air conditioning we have found cavity ambient temperatures up to 30 degrees higher than the room temperature. We wish to emphasize that our tables are corrected to 80 F and that therefore the careful designer will employ a downward correction of the coefficients for cases where temperatures exceed this value.

Dr. Spencer's objections to the presently accepted designation of room proportions have been answered before. Our data can be presented on any basis, but we believe that the distance from luminous ceiling to desk top is the important distance with respect to utilization because most of the lumens on the work plane arrive directly from the ceiling. We have pointed out elsewhere[1] that this well understood Room Ratio is a perfectly logical one from the standpoint of utilization. Whether the numerical values correspond in order with obsolescent letter indices doesn't seem too important.

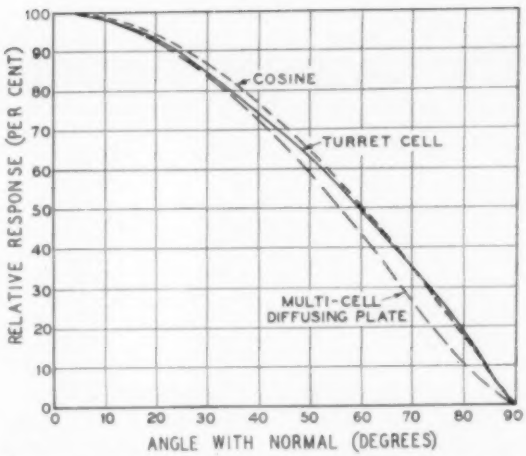

Figure A. Cosine response of turret type light cell used in laboratory measurements compared to theoretical cosine curve and to the response of a standard multicell diffusing plate instrument.

In reply to Dr. Spencer's question concerning our reflectance and transmittance values, the resulting discrepancies with the two instruments she mentions were such as might be expected with the diffusing materials involved in the study. Consequently, it appeared that the measurements of these materials with the Baumgartner Reflectometer would represent the higher degree of accuracy. Consideration was given also to the fact that a previous study of ceiling lighting,[2] in which a verification of the interflection equations was obtained, included measurements with this instrument. Furthermore, it should be noted that in the present paper the sum of transmittance and reflectance values subtracted from unity result in absorption values of roughly 10 per cent for plastics — a value previously mentioned by Dr. Spencer as typical.[3] The non-selective character of room surfaces and the fairly neutral quality of the plastic diffusers have greatly minimized the problem of color differences between fluorescent room light (warm white) and the incandescent lamp employed in the Reflectometer.

Dr. Spencer stated that the agreement between measurements and calculations was gratifying, particularly as a sequel to the 30 per cent errors which Dr. Wiseman felt were indicated last year. We find no such discrepancy in Dr. Wiseman's work[4] on f_2 (the luminous ceiling utilization factor); his measured values of f_2 differed on the average about 3 per cent from the computed values.

With regard to Dr. Spencer's comments on the accuracy of cosine correction of the light cell used for our tests, we have presented its cosine response in Fig. A. Note the excellent agreement between the curves for "turret cell" (used for our measurements) and "cosine," particularly at large angles of incidence.

1. Discussion by D. E. Spencer and Rebuttal by W. M. Potter and A. H. Russell of "Measured Utilization Factors," ILLUMINATING ENGINEERING, Vol. XLIX, p. 137 (March 1954).
2. See reference 26 of the paper.
3. See reference 10 of the paper.
4. Wiseman, Robert Swern: "Brightness and Illumination by Interreflections in Enclosures," ILLUMINATING ENGINEERING, Vol. L, p. 227 (May 1955).

The Case for Sloping Windows

By KENNETH C. WELCH

The author, well known for his studies of veiling glare on store windows, discusses problems arising from recent trends in store construction and techniques for eliminating window reflections, involving sloping glass windows and computed sun angles.

SOME NINE YEARS ago considerable study was given to veiling glare on show windows of retail stores, and how to overcome it. Basic principles as published then[1] still apply. Those studies determined the conditions that produced what we called "the threshold of harmful veiling glare," and the conditions where visibility through the glass would cease and its function as a mirror would take over. These conditions are reviewed here in the series of pictures shown in Figs. 1 and 2, using a model for controlled conditions.

New Problems

Naturally the principles involved still apply — but in the intervening nine years since their publication, new circumstances have developed in the field of fenestration. One new circumstance in the retail store field, for example, is the trend to suburban shopping centers. These are nearly always low buildings out in the open country — reflecting from their vertical glass windows all the brightnesses in nature (Fig. 3). Such a condition is, of course, a complete visual barrier.

One solution to this problem, for some of the newer shopping centers, has been a trend toward air-conditioned pedestrian "main streets," often on two levels. With this type of structure, it is possible (and economically feasible to create a perpetual springtime climate, so that individual stores can use roll-up glazed doors (like the typical garage door) rather than glass enclosures. Such a system eliminates all barriers, visual or otherwise. It permits selling directly on the "street" and takes maximum advantage of impulse sales. With this new architectural "vending machine" concept, glass is still used — but as an exterior wall toward the parking area. Often this can be geometrically disposed to reflect lower brightnesses.

AUTHOR: Architect, Grand Rapids, Mich.

Sloping Glass Windows

As determined by previous studies, brightness created on a store window display must equal that reflected in the glass. When the brightness reflected is five times that being viewed through the glass, "veiling glare" completely obliterates the display, or the interior of the store in the case of the so-called open front. Brightnesses in nature come high; something like 8000 ft-L on white clouds; a hazy sky is commonly 2000 to 2500 ft-L; sunlight

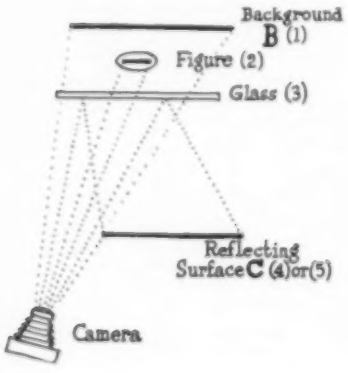

Figure 1. How the photographs of Fig. 2 were taken. The model consists of (1) a light background of approximately 0.84 diffused reflection with a black "B" on it, of approximately 0.04 reflectance. (2) A photographic cut-out figure about 6 inches high, the lightest part of which had a diffused reflectance of 0.74. (3) A polished piece of plate glass which reflected (4) a white surface of 0.84 reflectance with a black "C" of 0.04 reflectance painted on it. This appears as a light square when brightly illuminated on the glass surface. There was (5) an alternate black surface with a white "C" which took the place of (4) in Figs. 2a, b and c.

Figure 2A. Here the alternate black surface (5) is being reflected. The ratio of brightness between the background (1) B, and the reflected area (5) C black surface is approximately 30 to 1. This approaches a condition found at night with an artificially lighted display, and except for brightness patterns of reflected light (signs, etc.) that might disturb this pattern, it is our best lighting condition for window display for "open fronts."

Figure 2B. The brightness in the "display window" has been reduced, and the exterior brightness, as reflected in the glass, increased. A ratio of background to area C is approximately 7.5 to 1. The glass is still reflecting on the black area (5) but note that the white C which has a brightness 3.5 times the background is just beginning to show up. This is just beyond our "threshold of veiling glare" mentioned nine years ago.

Figure 2C. The ratio between the light background (measured just inside the letter B) and the black C reflecting area is 1.3. The display is still satisfactory, but the white C with the ratio of 0.45 produces a disturbing pattern. Even when large areas of lower brightness are reflected, smaller areas like this reflected letter C (22 times brighter than the black background B) can be harmful to a merchandise display.

Figure 2D. The model here is reflecting the white area (4) C, and the ratio is 50 to 1. This would not be too serious if the reflected area were a plain surface, but the introduction of brightness contrast, as for example letter C, can be disturbing. The double reflection on the reflected letter C in the plate glass is exaggerated because the glass of the mock-up was ¼-inch thick; to be in scale it should be 0.3-inch thick.

Figure 2E. Here we have a ratio between the illuminated background and figure to the reflecting surface of 1 to 25. All brightness readings were taken in the middle area of the letters B and C. In this case a very destructive veiling glare destroys the value of the display. Note how the detail of the figure can be seen, however, in that portion which reflects the letter C, which is of much lower brightness.

Figure 2F. Here the ratio is 1 to 36, akin to 120 footcandles illumination creating a brightness of 83 footlamberts on an approximately 70 per cent reflectance garment, but trying to compete with 3000 footlamberts on a sun-lighted building across the street. The display at the point C (reversed) has all but disappeared.

Figure 3. Except for the few small wares low down in the window—which are daylighted—this "open front" only mirrors the parked cars.

Figure 4. Note that the lower two-thirds of this sloped window area reflects only the low-brightness shaded side-walk, permitting a much better than average view of the store interior, and of the form displays adjacent to the glass. The upper portion (above normal viewing distance, however, and above the display-interest level) reflects the sunlighted street, mirroring the photographer and his parked car.

on a cement walk can produce 1500 ft-L. With vertical glass windows and outside brightnesses of this order, interior illumination of a show window or store should be of the order of an economically difficult 500 to 1000 footeandles[2] for daytime viewing, to offset the veiling effect of a window reflecting high surrounding brightnesses from the street and sky.

Several recent shopping centers, notably a new one in Omaha which opened last September 1st, have employed the technique of sloping the glass inward at the bottom at an angle which reflects brightnesses of only about 50 to 80 footlamberts. Photographs of the Omaha store are not yet available, but Figs. 4 and 5, showing an open-front store in Grand Haven, Michigan, illustrate the effectiveness of this method of minimizing window reflections. A similar method has been used for the show window of Siegl's in Grand Rapids, Fig. 6. Note the reflected sunlight above the display in Siegl's show window. Brightness readings, taken at 4:45 p.m. EST, the last of May in Grand Rapids, Michigan, were as follows: Sunlighted red brick pavement, 510 ft-L average; sidewalks in shade 120 to 140 ft-L; sidewalk in sun 1000 to 1270 ft-L; sunlighted building across the street and light-colored car, 540 to 570 ft-L; sky at zenith, 1600 ft-L. Inside the window, the background measures 115 ft-L average; the white garment on the floor, lower left corner is 130 ft-L. Thus it can be seen that for the display proper, the brightness of the brightest object inside is almost the same as the brightness being reflected (with sloping glass this is the 120 ft-L shaded sidewalk). This is a condition which produces an easily seen display.

The problem of veiling glare is not exclusive with show windows. In modern-living architecture, with the new concept of spatial relationships, large areas of glass are essential. One hundred fifty years ago the Cape Cod cottage was a magnificent conception, both functionally and esthetically. Glass could then only be made in small wavy pieces, and fire places furnished the wintertime heat. Outdoor views did not exist, except outdoors, or very close to one of the windows. Modern insulated glass and modern air-conditioning has freed the architect from this largely emotional, traditional approach to our sheltered environment.

Further, with increased efficiency and improved control of electric illumination, we are free to

Figure 5. (left) The same store as in Fig. 4 is shown, for contrast, with its next-door neighbor. The vertical glass of the store on the left is a perfect mirror, its interior totally obstructed and only a few daylighted objects of its display to be seen.

consider glass areas primarily for view rather than for light.[3] Here again, however, veiling glare may defeat our purpose. No view exists, however big the glass or beautiful the garden, if high brightnesses within the room, reflected back to us from the vertical glass window, are all one sees. At nighttime, a balance between indoor and outdoor brightnesses may solve this problem.[4] Sloping the glass to the most effective angle offers another solution. Figs. 7, 8 and 9 show a residence in which sloping glass has been used to eliminate or materially reduce veiling glare.

With any method, however, the architect-engineer team must know their brightnesses. They must know which they can create, know those created by nature, and those that their non-controllable neighbors will produce.

Figure 6. Sloping glass window reflects only low brightness of shaded side-walk (120 ft-L) in the main display area. Highest brightness inside the window is 130 ft-L, creating a desirable condition for unobstructed view of the display.

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2. *I.E.S. Lighting Handbook*, Second Edition, page 10-88, Illuminating Engineering Society, 1860 Broadway, New York, N. Y.
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Figure 7. (right) A residence in which sloping glass windows and indoor-outdoor brightnesses have been balanced for unobstructed view of outdoor scene.

Figure 8. (below) Close-up of the daytime view.

Figure 9. (below right) Close-up of view from the same position at night during a thunderstorm.

Daylighting Plus Incandescent . . . in an engineered design

By B. T. HEINZ

COLLABORATION with the lighting engineer from the drawing-board onward, was invited by the architect of this school project in Lynwood, Washington. Problems encountered, both structural and in connection with the basic illumination design, were met by joint development of basic objectives.

The basic floor plan standardized on classrooms 28 feet by 32 feet arranged with the corridors at one end and the windows at the other. Some rooms ear larger and a few smaller, but all are in multip'es of four-foot modules for simplicity of construction. A full sawtooth structure with northeast exposure is used for some sections. In others, clerestory construction was used, and in other areas, flat roofs with plastic sky domes.

Foremost objective of the lighting design was for approved quality and quantity, architecturally suited to the building structure and so designed as to complement the several methods of natural lighting. In Washington, the mandatory minimum level to be maintained in service is 25 footcandles, and as these junior high classrooms were to be used only in the day time and excellent natural lighting was provided, this became the design level. Incandescent lighting was to be used, with the thought that if at any later time the need for 60 or more footcandles were felt, it would require only a change to fluorescent fixtures, since the wiring capacity would already have been provided.

A second major objective of the lighting system was ease of maintenance. A third was our old friend, economy; the complete school plant cost had to come within the $13.00 per square foot limit against which the state of Washington was matching school funds at the time.

Classroom in area having clerestory windows. Units are surface-mounted on the acoustical tiled roof decking, and suspended in the clerestory.

Gymnasium, having also fully equipped stage. Lighting is from 750-watt high bay porcelain reflectors with glass roundels, on disconnecting and lowering fixture hangers.

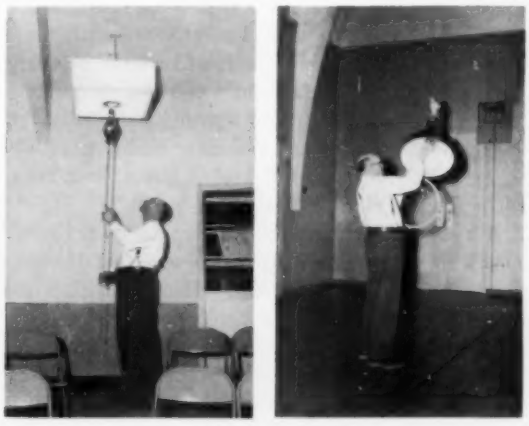
The lighting system features the louvered unit shown in the photograph. It consists of a shallow dome-shaped 24-inch square reflector equipped with an eggcrate louver and a silvered bowl lamp. Twelve 300-watt units per room are in eight-foot by nine-foot four-inch centers. In applying this basic pattern to the three different roof structures, different mounting methods had to be used for proper spacing. In the area having sawtooth roof, side mounting, an innovation for these luminaires, was made at the base supports of the sawtooth roof sections. In some rooms, units were both side mounted and suspended. In all cases, the fixtures were equipped with special covers to prevent accumulation of dirt, and to foil the spitball marksmanship of the pupils.

In the clerestoried rooms, units are surface mounted on the 9-ft 1¼-inch acoustical tiled roof decking, and suspended in the clerestory. For the plastic-dome daylighted rooms, a pleasing harmony of pattern between the daylighting system and the electrical system is created with the square luminaire. In all areas, specially deep fixture mounting frames have been employed to bring the louvers level with the beams and to prevent excessive brightness which might be thrown on the side of a beam if too close to a shallower fixture.

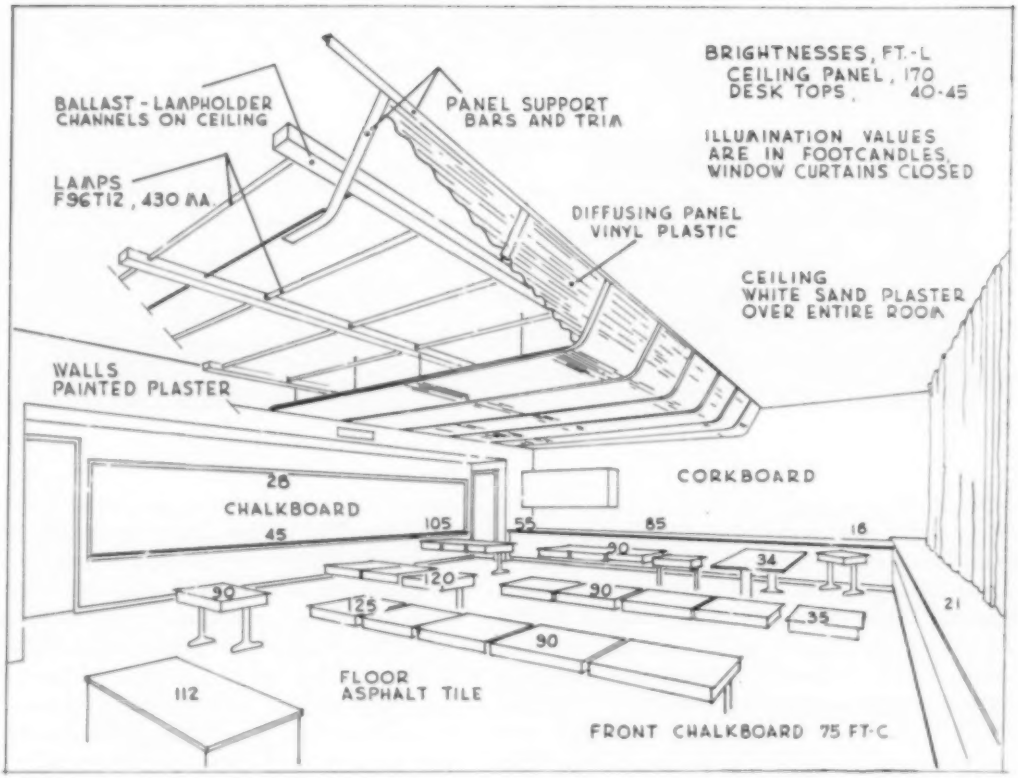
All three objectives for the installation were met with this system, an added satisfaction coming from the expressed pleasure of the school executives.

AUTHOR: B. T. Heinz Company, Seattle, Washington. Architects, Johnson and Botesch, Everett, Wash.; John Chaffer, electrical engineer. This installation took first prize in the MMILJ contest conducted by the Puget Sound Section; second prize at the 1955 Regional Conference.

Home economics room. In all areas, deep fixture mounting frames bring the louvers level with the beams, to prevent excessive brightness on beam sides.



Maintenance. At left, silvered-bowl lamp replacement is easily and safely effected with suction-cup pole. At right, disconnecting hangers in gymnasium and stage.



Illumination levels at night with curtains closed. Under daylight conditions, footcandle values level out

Luminous Element Plus Controlled Daylight . . .

SCHOOL BOARDS, almost without exception, must present to the engineer the old familiar lighting design problem — the best possible illumination with economy. More and more school boards, happily, consider "economy" a relative term meaning "overall cost for good light" and not "minimum installation cost." For the lighting installation in a group of classrooms of a new addition to the Gansevoort Elementary School at Rome, New York, such was the view of the school board.

A typical classroom in this school is 29 by 30 feet, a total area of nearly 900 square feet. Ceiling height is ten feet six inches. High level illumination with a minimum of brightness contrast has been provided, using the luminous panel type of lighting. Considerable savings in costs were effected by a design which applied this system over a partial area of the completely finished ceiling, utilizing the daylight on the window side of the room in the overall lighting pattern. Our cost investigations showed that a full-plastered ceiling is only slightly more expensive in this connection than an unfinished plenum, when painting of the exposed deck and the structure are considered.

The overall lighting design, as mentioned, is predicated on the use of daylight. In the Central New York area we find that the average cloudy winter day will produce during school hours between 100 and 200 footcandles at the window sill, dropping off to below ten footcandles at the far side of the room. Windows in these rooms are clear glass, full height from work top to ceiling; each room has white draw-curtains for sunlight control. Some also have darkening curtains for use with visual aid equipment. The specific design objective was, therefore, to supplement the minimum expected curtain-controlled daylight, with a luminaire on the inside of the room having proper output to produce a uniform light over the area.

The design is qualified as an elementary class-

across the entire room, and brightness ratios are further reduced.

equals modern lighting in a new school

mmilj

By ROBERT A. NEVIN

room simply because of this partial dependence on daylight for full use of the room. It will be noticed that while night usage would be very good for about two-thirds of the room, such use might be slightly limited by the drop off in illumination on the window side. This is of no importance since the room furniture, including built-in worktops, is sized for elementary school children, and night use for adult purposes is not feasible.

Material used for the luminous panel is white corrugated vinyl plastic having 45 per cent transmission, 47 per cent reflection, 8 per cent absorption. This sheeting is supported on runner bars 18 inches below the ceiling, and returned up to the ceiling at the outside edge. As is often the case in this type of design, the available vertical distance between panel and lamps limited the maximum lamp spacing, consequently increasing the footcandle level. As there appeared to be no economic or technical advantage in reducing lamp current, the lamps were left at full brightness, 425 ma. Each room has 24 eight-foot lamps spaced 29 inches on center in two rows. The lamp structure and the panel form a luminaire 18 feet wide on the corridor side, and extending the full length of the room. The outside edge of the panel is about eight feet from the window wall, equal to the window height above the working level.

Calculated maintained level was 110 footcandles. This value was very closely realized in the installation, even under the least favorable circumstances of total outside darkness. Footcandle measurements shown in the drawing were taken at night after about 100 hours of operation, with the white curtains closed. A level of 120 footcandles was found under the center of the panel, coinciding closely with the design figure. Under the panel

AUTHOR: Sargent, Webster, Crenshaw & Folley, Architects, Syracuse, N. Y. This installation won first place in the 1955 MMILJ contest of the Central New York Section.

edge the value is 90 footcandles, and under the corners 55 to 70. The main chalkboard receives about 75 footcandles, the one at the inside of the room 30 to 45. The window sill worktop receives 21 footcandles, desks between sill and panel edge about 35, under these circumstances. Brightness of the panel itself is 170 footlamberts when viewed straight up, and brightness ratios of all surfaces are well within the standard recommended limits.

These conditions are the least favorable possible, and are of only technical interest. The introduction of daylight acts to level out the footcandle values across the entire room, so that all brightness ratios are further reduced and the comfort index correspondingly increased. This is the condition existing during normal use of the building.

Utility Lights Its Dispatch Room

A level of 50 footcandles on the vertical surface of the dispatch board is achieved in the load dispatch room of the Pacific Power and Light Company main offices in Portland, Ore., with 95 footcandles on the horizontal.

The 2-by-4-foot fixtures, with two-foot square modular vinyl plastic diffusers, are mounted in rows in a pattern roughly following the contour of the semicircular dispatch board. The units, using two 40-watt rapid start lamps, are surface-mounted on the 9-foot 4-inch ceiling. Spacing between rows is two feet.

The dispatch board is green, 18% RF; lines and markings, indicating various voltages, on the board are in six colors — white, yellow, light green, light blue, black and red — especially selected for contrast with the board. Floors are gray, 25% RF; desk tops are gray, 36% RF; and the ceiling is of white acoustical tile.

A few PAR lamps mounted over the center of the board are connected to d-c supply for emergency use in case of a-c failure.

Installation designed by Frank Reis, Pacific Power & Light, with consultation on fixtures with A. G. Miller, Fluorescent Fixtures of California, Portland office. The installation won second prize in the Oregon Section's 1955 contest for My Most Interesting Lighting Job.

Color Rendition with Fluorescent Sources of Illumination

By HARRY HELSON
DEANE B. JUDD
MARTHA WILSON

Color and form are partners in producing the artistry of light. An outstanding feature of modern interiors is the striking use of color. It, together with new functional forms, sets the atmosphere or "feeling" of present day architecture. The former universal use of incandescent lamps greatly emphasized the yellows and reds. Fluorescent sources are now bringing emphasis to the blues and greens for richer, more satisfying color harmony. Distortion of anticipated appearance through use of certain light sources is to be avoided.

Dr. Harry Helson and his colleagues have completed a study of a method of predicting the changes in appearance as one goes from one light source to another. A chart showing maximum changes due to different observers has been made up.

The equations developed through this project enable one to predict the color of any object, viewed under any illuminant, as perceived by an observer adapted to that illuminant. This theory does not attempt to predict color changes due to the influence of backgrounds of different reflectances but experimental data for white, gray and black backgrounds were presented in an earlier paper. Tables based on the theory giving the color changes predicted for various light sources of commercial interest should be of considerable practical value to the illuminating engineer in helping the architect and interior designer to visualize the actual appearance of his chosen colors.

1. Introduction

IT IS COMMONLY recognized that objects have different colors in different source of illumination due to changes in the spectral energies of the light leaving the objects and to changes in sensitivity of the eye arising from alteration in the quantity or quality of light affecting the visual mechanism. In earlier studies of colors of objects in strongly chromatic illuminants (Helson, 1938; Helson and Jeffers, 1940; Judd, 1940), and of object colors in incandescent (tungsten) illuminants (Helson and Grove, 1947; Helson, Judd, and Warren, 1952), it was shown that good first-order predictions of hue, lightness, and saturation could be made by taking into account the changed visual adaptation to the non-daylight viewing conditions as compared with daylight adaptation. The present study extends the former investigations into the field of fluorescent illumination partly because of the widsspread use of fluorescent sources in daily life and partly because of the peculiar nature of their spectral-energy distributions as compared with either daylight or incandescent sources. It is not known if formulations based on sources of fairly smooth spectral distributions of energy, such as tungsten or daylight, carry over to sources of the irregular energy distributions found with fluorescent lamps.

This investigation is concerned with the application of formulas previously found adequate in specifying the colors of objects in incandescent illumination (Helson, Judd, and Warren, 1952) to three representative types of fluorescent illumina-

AUTHORS: Harry Helson, Professor of Psychology, University of Texas; Deane B. Judd, Physicist, National Bureau of Standards; Martha Wilson, Research Scientist, University of Texas. This study represents the second and final phase of Project #11-B carried out with the support of a grant from the I.E.S. Research Fund for the purpose of evaluating the effect of fluorescent illumination on color rendition.

Figure 1. Showing the relation between the Munsell and psychological color circles. The Munsell hue circle employs five primary hues; the psychological hue circle has four primary hues.

tion. These formulas take into account the changed state of adaptation of the visual mechanism in passing from daylight to the fluorescent illuminants. This approach is important in the development of quantitative predictions of the colors of objects in various illuminants and in the determination of the primaries necessary to account for the results of changes in visual adaptation arising from altered spectral energy distributions of sources, from effects of backgrounds against which objects are viewed, or from other changes in viewing conditions which affect the adaptive state of the eye. Here only the spectral energy distribution of the source is the variable under study.

2. Method

In order to obtain reliable estimates of colors under different sources, observers were trained in a modified Munsell system of color nomenclature similar to the one used in a previous study (Helson, Judd, Warren, 1952). The modified system employs the four psychological primaries, red, yellow, green and blue and mixtures of the four. The hue circle given in Fig. 1 shows how a simple correspondence was established between this system, which may be called the psychological system, and the Munsell system so that the final judgments could be expressed in Munsell renotation (Newhall, Nickerson and Judd, 1943). The psychological system takes account of the observers' intuitive notion of blue which does not correspond with the Munsell hue for blue, and treats the Munsell purple region of the hue circle as a combination of red and blue rather than as a fifth primary. Thus, while the two systems agree in the red, yellow, and green regions, they diverge in the blue and purple regions since one hue step in the psychological system must cover two hue steps in the Munsell system as shown in Fig. 1. For example, in the modified system, the term red-blue covers the Munsell designations of purple and reddish-purple. To take care of this difference the Munsell numerical notations for these hues, 85.0 and 87.5, were averaged to give 86.3 and this number was taken as the numerical notation for red-blue in the psychological system. The hue circle in the modified system was divided into thirty-two steps and observers gave judgments in terms of this qualitative scheme which was then translated into the Munsell numerical notation for computational purposes. The Munsell system was used in training observers to report on lightness and saturation. Lightness was judged on a scale from 0 to 10 and saturation on a scale from 0 to 15.

The observers were five psychology students at the University of Texas. They required an average of eight hours of training to reach the criterion demanded for this study, *viz.*, estimating colors within 2.5 Munsell hue steps and one Munsell value and chroma step. Preliminary observations were also made by a sixth observer, who, however, failed to qualify, and whose results were therefore omitted from the tabulated averages. The observers were trained by methods described in an earlier study of color changes in passing from daylight to incandescent-lamp illumination (Helson, Judd, Warren, 1952). The training sessions took place in a room with a northern exposure to approximate the conditions of standardization by which the Munsell renotations were determined.

The observations under fluorescent sources were made in a light-tight booth supplied with a standard two-lamp fluorescent fixture. The walls and shelf in the booth were lined with non-selective gray cardboard. A fan was placed in the booth to maintain a fairly constant ambient temperature. A current of between 0.80 and 0.82 amperes was supplied to the primary of the ballast of the fixture. The rated primary current is 0.84 ampere. The spectral energy distributions of the three fluorescent sources are shown in Fig. 2. The observers made their estimates of the samples (described later) successively under the 3500K, 6500K and 4500K fluorescent sources. For judgments of daylight colors the fluorescent fixture was replaced by two standard Macbeth daylight lamps approxi-

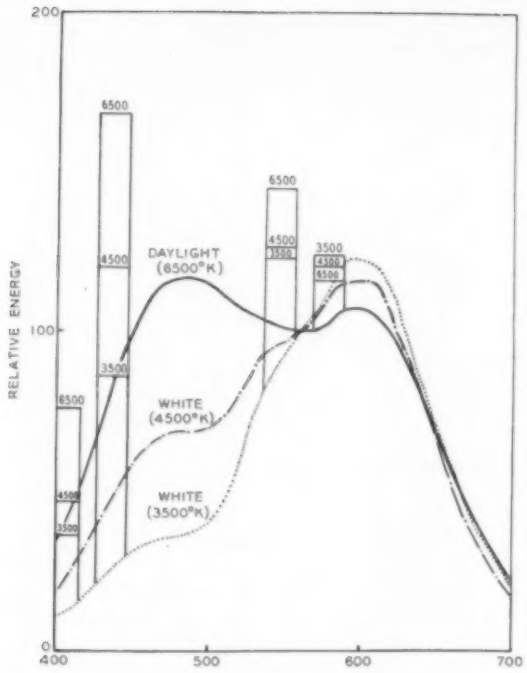


Figure 2. Spectral energy distributions of the fluorescent sources.

mating 6500K and the observations were repeated. Illuminations on the sample plane from the four sources are given in Table I.

TABLE I — Illuminations on the Sample Plane.

Source	Illumination (ft-c)
3500K fluorescent	32.0
4500K fluorescent	30.0
6500K fluorescent	27.0
Macbeth daylight (incandescent lamp plus Corning Daylite filter)	37.0

The observers adapted to the illumination in the booth for five minutes before the observations were made. Two sessions of about 45 minutes each were necessary to complete the observations for each source by one subject. One hundred thirty standard Munsell samples were chosen to give the maximum range of lightness and saturation in various combinations for the ten major Munsell hues given in Tables II, III, and IV. The samples were 1¼ by 1¼ inches and were mounted on gray cardboard similar to that which lined the walls of the booth. The 130 samples were randomized for each subject under each illuminant to minimize contrast effects. Twenty samples were exposed at one time. The tristimulus values of the 130 Munsell samples in the three illuminants are given in a paper by Nickerson and Wilson (1950). The observed hues given in Tables II, III and IV in Munsell terms have been corrected to take account of the difference between the observer's own scale of hues and the Munsell renotated hue scale. The five estimates of each sample as judged under Macbeth daylight were averaged to give the mean judgment. This mean judgment was compared with the Munsell renotation for source C to find the difference by which the fluorescent judgments would be expected to depart from Munsell renotation derived for the fluorescent sources. Thus, if the Munsell renotation of a given sample were 5.0R and the observers' mean judgment under Macbeth daylight were 6.0R, a correction of −1.0 would be applied to the mean judgments of that sample under the fluorescent sources. Corrections were calculated in this way for the hue, lightness and saturation of each sample, and were applied to the mean judgments obtained under the fluorescent sources. The extreme judgments showing the range of observer estimates were corrected by applying the same average corrections. The corrections did not always improve the agreement between observed mean hues and the predicted hues but in most cases the rationale seemed warranted since it resulted in better agreement between theory and observation. A similar procedure was followed by Bouma and Kruithof (1947/1948).

3. Results and Discussion

In Tables II, III and IV are given the average and inter-observer range of estimates of hue, lightness and saturation by five observers and the theoretical predictions of 130 Munsell samples viewed against gray background with 6500K, 4500K, and 3500K fluorescent sources of illumination. In general, the hue changes, as summarized for five observers in Table V and as shown for six observers in Fig. 3, are in clockwise direction around the hue circle as one goes from daylight (here taken as Munsell renotation) to each of the fluorescent sources. Thus the red and yellow-red hues become yellower, the green-yellows become greener, the greens and blue-greens become bluer, and the blues, purple-blues, purples and red-purples become redder, except for the blues in 6500K which become slightly greener. The hue shifts are remarkably small on the average considering the common belief that fluorescent light results in considerable distortion of colors. They are generally less than 2.50 in the numerical Munsell hue scale. The average observed hue shift from daylight to 6500K is 0.70, to 4500K it is 0.61, and to 3500K, it is 1.84. It is seen that these changes represent differences less than the change from red to yellowish red, or from

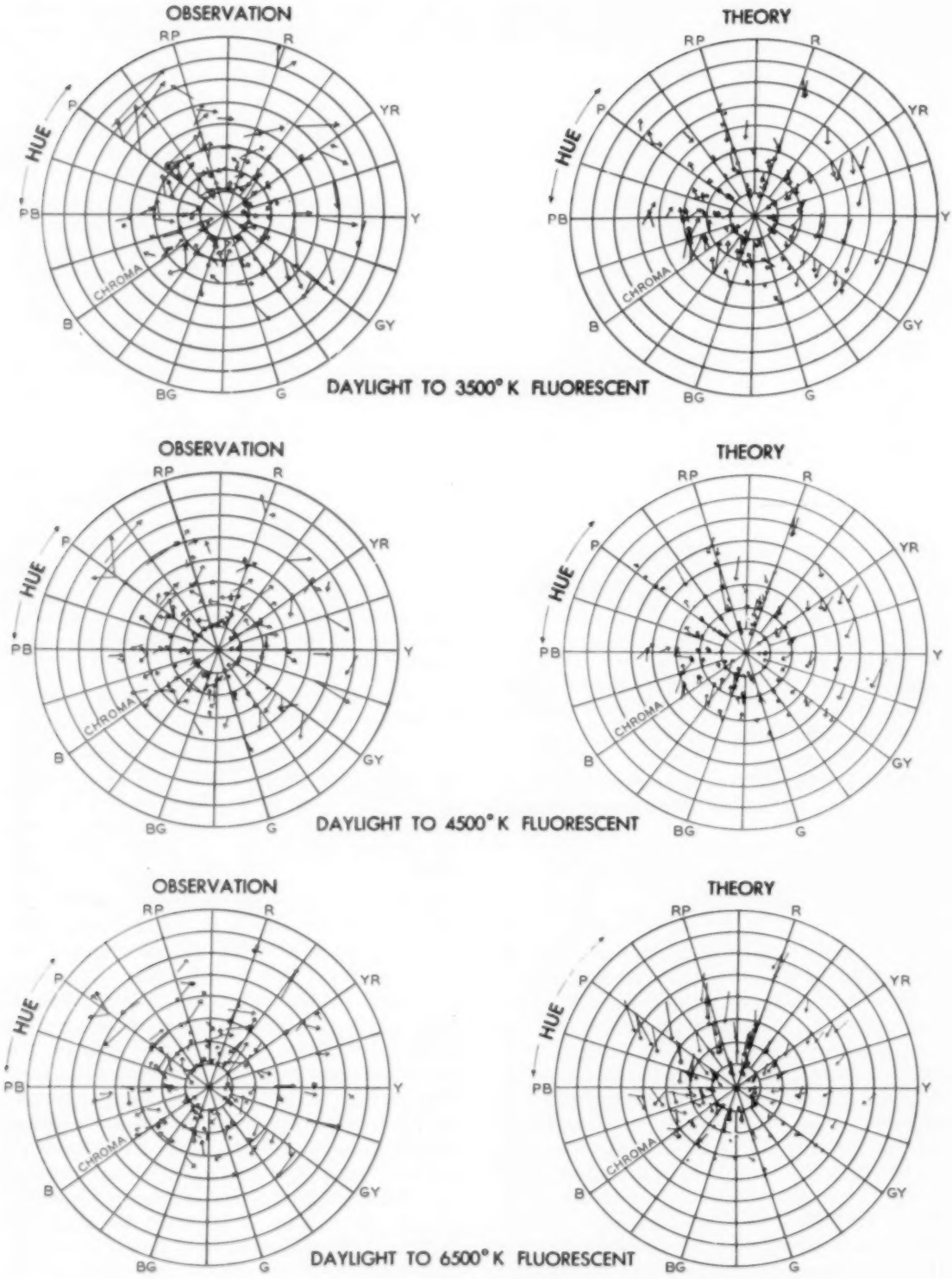


Figure 3. Changes in hue and saturation of 130 Munsell samples in passing from daylight (initial points of vectors) to fluorescent illumination (terminal points of vectors) according to observation (average of six observers) and according to theory.

TABLE II — Observed and Computed Hue, Lightness and Saturation, and Observers' Range under 6500K Fluorescent Illumination.

Munsell Renotation H	V/C	Observed H	L/S	Observers' Range H	S	Computed H	L/S
3.5R	2.3/2.2	10.0R	1.9/2.5	6.0R — 3.5YR	1.0 — 4.0	6.3R	2.3/1.2
3.0R	2.5/4.8	6.3R	2.6/5.1	3.2R — 0.7YR	3.9 — 5.9	2.0R	2.5/3.2
5.0R	3.2/7.4	4.2R	3.3/6.8	1.2R — 8.7R	4.8 — 9.8	4.4R	3.1/5.3
4.0R	5.0/2.8	2.3R	4.4/3.2	6.3RP — 8.8R	2.1 — 4.1	3.3R	5.0/2.5
3.5R	4.1/4.7	8.8RP	3.8/4.2	1.8RP — 3.0R	3.2 — 5.2	3.3R	4.0/3.9
4.0R	4.9/5.3	8.7R	4.6/5.6	4.7R — 2.2YR	4.8 — 6.8	3.8R	4.9/4.9
5.0R	4.2/12.6	4.8R	4.4/13.4	3.5R — 7.3R	9.8 — 15.8	5.0R	4.1/10.6
5.5R	5.0/12.8	4.5R	5.0/12.8	4.0R — 6.5R	10.8 — 15.8	4.7R	4.9/10.9
2.5R	7.2/2.6	0.8R	7.6/2.1	4.8RP — 3.5R	1.1 — 4.1	2.5R	7.1/2.3
3.5R	8.0/3.6	3.0R	8.2/3.6	1.5R — 4.0R	3.6 — 4.6	3.1R	8.0/3.3
3.0R	7.1/5.2	2.5R	7.6/5.1	6.8RP — 8.0R	4.6 — 5.6	2.5R	7.1/4.8
3.5R	7.0/7.0	8.2R	7.3/7.6	5.7R — 0.7YR	5.2 — 10.2	2.8R	6.9/6.3
10.0R	3.3/5.4	9.0R	3.7/7.2	9.0R — 9.0R	6.2 — 8.2	9.3R	3.3/5.5
9.5R	5.1/4.9	8.3R	4.9/3.6	4.5R — 2.0YR	2.6 — 5.1	10.0R	5.0/4.3
0.5YR	6.2/10.1	10.0R	6.7/13.1	6.5R — 4.0YR	9.5 — 16.5	2.2YR	6.2/9.0
4.5YR	2.4/1.8	1.0YR	2.5/2.9	7.5R — 2.5Y	0.6 — 4.6	4.4YR	2.4/1.1
5.0YR	3.3/4.1	6.5YR	2.9/3.6	4.5YR — 4.5Y	2.4 — 5.4	4.9YR	3.3/3.1
4.0YR	4.9/2.1	2.5YR	5.2/1.5	9.5R — 4.5YR	0.1 — 3.1	3.8YR	4.9/1.8
4.5YR	4.9/4.6	4.5YR	4.7/4.5	0.5YR — 0.5Y	3.1 — 6.6	4.4YR	4.9/4.0
5.5YR	5.1/9.0	5.0YR	5.4/10.2	2.5YR — 7.5YR	8.4 — 12.4	5.7YR	5.1/7.6
3.0YR	7.0/2.1	3.5YR	7.6/2.0	7.5R — 10.0YR	1.2 — 2.2	3.0YR	7.0/2.1
4.0YR	8.0/3.5	10.0R	7.9/2.5	6.0R — 3.5YR	1.9 — 4.9	4.0YR	8.0/3.2
3.5YR	6.9/5.9	4.0YR	7.6/4.2	9.5R — 7.0YR	3.9 — 4.9	4.2YR	6.9/5.5
4.5YR	7.0/8.2	5.0YR	6.9/8.4	0.5YR — 8.0YR	5.6 — 13.6	5.0YR	7.0/7.5
5.5YR	6.9/10.1	7.0YR	7.3/11.1	5.0YR — 10.0YR	7.9 — 12.9	9.6YR	6.9/9.8
6.0YR	6.2/11.5	5.0YR	5.8/11.5	5.0YR — 5.0YR	9.7 — 14.7	6.2YR	6.2/10.0
10.0YR	4.2/4.6	1.5Y	4.8/5.6	8.5YR — 3.5Y	3.3 — 8.3	9.9YR	4.2/3.8
10.0YR	5.1/4.4	2.0Y	5.1/4.8	4.5YR — 7.0Y	3.8 — 6.8	0.3Y	5.1/3.9
10.0YR	6.5/9.8	0.5Y	6.5/9.9	8.5YR — 1.0Y	4.7 — 15.7	1.0Y	6.5/8.8
5.0Y	2.5/1.4	2.0Y	2.6/1.7	3.5YR — 1.0GY	0.6 — 3.6	4.4Y	2.5/0.9
4.5Y	5.2/1.7	7.0Y	5.0/1.9	9.5YR — 9.5GY	1.3 — 2.3	5.4Y	5.1/1.5
5.0Y	4.1/3.6	7.5Y	3.9/3.6	9.5YR — 4.5GY	3.0 — 4.5	5.5Y	4.1/3.1
6.0Y	5.0/6.0	8.0Y	5.0/6.5	2.0Y — 2.0GY	4.3 — 9.3	6.4Y	5.0/5.2
3.5Y	7.8/1.6	7.0Y	8.3/1.4	9.0R — 6.5G	1.4 — 1.4	3.9Y	7.8/1.7
4.5Y	7.9/5.8	4.5Y	7.4/7.4	2.5Y — 5.0Y	4.6 — 9.6	5.5Y	8.0/5.5
5.5Y	7.9/12.3	6.0Y	7.6/12.7	5.0Y — 7.5Y	9.7 — 15.7	6.5Y	7.9/11.2
5.5Y	7.9/8.3	6.0Y	7.9/9.5	6.0Y — 6.0Y	8.7 — 12.7	6.3Y	7.9/7.7
0.5GY	3.3/1.8	1.0GY	3.5/1.7	3.5Y — 8.5GY	0.3 — 2.3	0.7GY	3.3/1.5
10.0Y	4.3/3.7	1.5GY	4.3/3.6	4.5Y — 9.5GY	2.4 — 4.4	0.4GY	4.3/3.2
0.5GY	8.1/9.1	9.5Y	8.3/12.1	8.0Y — 3.0GY	8.7 — 15.7	0.8GY	8.1/8.8
5.5GY	2.5/2.2	5.0GY	2.3/2.5	9.0Y — 9.0GY	0.6 — 4.6	5.4GY	2.5/1.5
5.0GY	5.1/2.0	4.0GY	5.1/1.5	7.5Y — 2.5G	1.3 — 2.3	5.1GY	5.1/1.8
5.0GY	5.1/5.4	8.0GY	4.9/5.8	4.0GY — 9.0GY	4.4 — 8.4	5.5GY	5.1/5.0
5.0GY	5.1/7.1	6.5GY	4.9/7.3	3.5GY — 8.5GY	5.7 — 11.7	5.3GY	5.2/6.4
5.5GY	7.0/1.8	3.0G	7.3/2.4	8.0Y — 9.3G	1.4 — 4.4	5.0GY	7.0/1.7
4.0GY	7.0/9.5	9.5GY	6.6/10.0	5.5GY — 3.0G	8.0 — 11.5	4.3GY	7.0/9.1
5.0GY	7.1/6.4	10.0GY	6.9/7.7	4.0GY — 4.0G	6.7 — 8.7	5.2GY	7.1/6.4
6.0GY	8.1/3.6	9.0Y	8.8/3.1	7.0Y — 2.0GY	2.9 — 3.9	5.8GY	8.1/3.5
4.5GY	8.1/8.7	7.0GY	8.1/9.4	5.0GY — 2.5G	6.6 — 11.6	5.0GY	8.1/8.4
10.0GY	4.2/5.4	9.0GY	4.6/6.0	3.0GY — 0.5G	4.0 — 10.0	0.1G	4.2/4.7
10.0GY	5.0/4.3	1.0G	4.9/3.7	8.5GY — 3.5G	2.1 — 5.1	10.0GY	5.1/4.0
10.0GY	7.1/6.5	1.0G	7.1/7.0	6.5GY — 4.0G	5.2 — 8.2	10.0GY	7.2/6.5
7.0G	2.2/2.4	9.3G	1.9/1.9	8.5G — 2.3BG	1.1 — 3.1	6.7G	2.2/1.5
4.0G	3.3/4.8	3.5G	3.2/4.8	10.0GY — 5.0G	3.2 — 6.2	3.9G	3.3/3.7
6.5G	4.9/2.4	4.0G	4.7/2.6	8.7GY — 2.5BG	1.6 — 4.1	5.8G	4.9/2.1
5.0G	4.9/4.8	2.3G	5.2/3.8	0.5G — 6.8G	2.2 — 5.2	4.1G	4.9/4.2
5.0G	4.9/8.2	5.5G	5.1/8.0	3.5G — 6.0G	6.6 — 9.6	4.4G	4.9/6.9
6.5G	7.0/2.1	6.5G	7.6/1.9	5.5GY — 0.5B	0.9 — 2.9	5.0G	7.0/2.0
7.0G	7.0/6.1	8.2G	6.9/6.4	0.2G — 7.7BG	5.2 — 8.2	6.1G	7.2/5.5
6.0G	8.7/2.7	9.0G	8.7/3.2	10.0GY — 5.0BG	2.7 — 4.2	5.0G	8.7/2.0
10.0G	3.2/4.7	1.7BG	3.5/3.5	9.2G — 8.0BG	2.3 — 4.3	9.7G	3.2/3.1
0.5BG	4.1/4.5	10.0G	4.1/4.3	5.7G — 2.0BG	3.9 — 4.9	10.0G	4.1/3.7
1.0BG	6.4/6.0	1.8BG	6.8/4.8	1.8BG — 1.8BG	4.2 — 6.2	9.8G	6.4/5.3
4.5BG	2.2/2.5	3.8BG	2.2/3.7	3.0BG — 6.8BG	2.9 — 5.9	4.6BG	2.2/1.4
5.0BG	2.3/3.7	4.0BG	2.5/5.1	2.5BG — 6.3BG	3.9 — 6.9	5.4BG	2.2/2.1
5.5BG	4.3/2.5	10.0BG	4.5/2.4	3.0BG — 6.7B	1.0 — 3.5	5.0BG	4.2/2.0
5.5BG	4.3/4.0	6.3BG	3.9/3.9	8.0G — 5.5B	2.7 — 4.7	5.2BG	4.3/3.2
5.0BG	5.1/6.4	2.5BG	5.7/7.1	5.7G — 3.2B	3.7 — 12.7	5.1BG	5.1/5.7
2.0BG	6.4/4.5	5.2BG	6.9/4.3	6.2G — 6.2B	2.9 — 5.9	1.4BG	6.3/3.9
3.5BG	7.3/2.1	9.0BG	8.0/2.0	8.5GY — 6.0B	1.3 — 2.8	2.7BG	7.3/1.8
4.5BG	7.2/3.4	7.7BG	7.3/3.0	9.7GY — 4.7B	1.0 — 4.0	4.8BG	7.2/2.8
4.5BG	5.1/2.5	3.3BG	3.9/2.7	6.5G — 9.0BG	1.8 — 4.8	3.8BG	5.1/2.3
9.5BG	3.2/5.8	3.0B	3.3/5.8	3.0BG — 9.2B	2.8 — 9.8	0.5B	3.1/3.9
9.5BG	4.1/4.0	8.2BG	4.3/4.2	4.2G — 4.2B	3.2 — 5.2	0.1B	4.1/3.1
10.0BG	6.3/5.8	9.0BG	6.8/6.6	5.0BG — 2.5B	3.6 — 8.6	0.2B	6.3/5.0
2.0B	2.2/2.2	6.5BG	2.2/2.6	3.2BG — 2.0B	1.6 — 4.6	2.2B	2.1/1.6
5.0B	3.1/2.3	5.3B	3.2/1.4	2.0B — 3.3PB	0.2 — 2.8	7.5B	3.2/1.7
6.5B	4.9/2.6	5.5B	4.8/2.2	10.0PB 2.2/5.5 10.0B	1.4 — 4.4	7.5B	4.9/2.3
5.5B	5.0/5.1	4.0B	4.8/5.7	6.5BG — 9.0B	4.5 — 8.5	6.6B	5.0/4.3
6.5B	4.0/6.9	4.2B	4.1/7.3	4.2B — 4.2B	4.7 — 9.7	9.9B	3.9/5.1

(Table II continued on next page.)

TABLE II *(Continued).*

Munsell Renotation H	V/C	Observed H	L/S	Observers' Range H	S	Computed H	L/S
5.0B	5.0/6.8	5.5B	5.2/7.6	4.0B — 6.5B	5.6 — 10.6	6.3B	4.9/5.7
5.5B	6.1/6.4	4.0B	6.9/4.8	7.0BG — 7.0B	3.8 — 5.8	6.3B	6.1/5.6
4.0B	8.2/2.2	6.0B	8.5/2.0	6.0B — 6.0B	1.8 — 2.8	5.3B	8.2/2.0
5.0B	7.1/4.7	5.0B	7.2/4.6	3.0B — 5.5B	2.9 — 7.9	6.1B	7.1/4.1
9.5B	3.2/5.6	9.0B	3.3/6.7	2.5B — 2.5PB	3.5 — 11.5	1.1PB	3.2/4.5
0.5PB	4.2/4.1	10.0B	4.1/4.0	7.5B — 2.5PB	2.6 — 5.6	1.9PB	4.1/3 4
9.5B	7.2/5.7	8.0B	7.8/4.6	6.0B — 8.5B	2.4 — 5.9	0.6PB	7.2/5.3
4.5PB	2.2/2.6	4.0PB	2.4/3.5	2.0PB — 4.5PB	1.9 — 5.9	4.7PB	2.1/1.7
4.0PB	2.3/5.9	1.5PB	2.1/5.9	7.0B — 4.5PB	4.3 — 9.3	5.3PB	2.2/4.0
4.0PB	3.3/9.4	4.0PB	3.4/8.4	3.5PB — 6.0PB	5.8 — 12.8	5.9PB	3.2/8.0
5.0PB	4.2/4.3	6.0PB	4.4/3.6	3.5PB — 8.8PB	2.6 — 4.6	5.6PB	4.2/3.9
5.0PB	5.1/3 1	5.8PB	5.1/3.9	4.2PB — 8.0PB	3.3 — 5.3	5.9PB	5.1/2.9
4.0PB	5.3/6.2	4.5PB	5.4/5.2	4.5PB — 4.5PB	4.0 — 7.0	5.5PB	5.2/5.6
3.5PB	5.3/8.6	3.0PB	5.2/10.2	2.0PB — 4.5PB	6.6 — 11.6	4.6PB	5.2/7.9
5.0PB	8.3/3.2	6.3PB	8.9/3.2	1.7PB — 8.0P	2.8 — 3.8	5.5PB	8.2/3.0
4.0PB	7.2/5.6	4.5PB	7.6/5.3	2.5PB — 5.0PB	5.0 — 7.0	5.1PB	7.1/5.3
5.0PB	6.3/7.4	4.5PB	6.2/6.5	3.5PB — 6.0PB	4.7 — 9.2	5.0PB	6.2/6.2
10.0PB	2.2/4.5	1.5P	1.9/5.4	7.2PB — 1.0RP	3.4 — 7.4	0.1P	2.1/3.8
10.0PB	4.1/4.6	8.3PB	4.3/2.8	6.0PB — 9.8PB	2.1 — 3.6	0.5P	4.1/4.4
10.0PB	7.0/5.3	1.4P	7.8/5.0	7.1PB — 5.9P	4.2 — 6.2	1.5P	7.0/6.0
5.5P	2.1/2.9	8.2P	2.1/3.5	1.2P — 5.0RP	2.7 — 3.7	5.4P	2..1/1.9
5.0P	2.2/4.6	0.2P	2.7/5.7	6.2PB — 5.0P	3.9 — 8.9	4.2P	2.1/3.1
5.0P	3.3/11.2	4.0P	3.4/13.2	9.0PB — 9.0P	11.2 — 16.2	3.8P	3.1/8.9
5.0P	5.0/2.5	9.0P	4.2/1.8	10.0PB — 5.0RP	1.3 — 3.3	5.0P	5.0/2.4
5.0P	5.0/6 8	9.5P	6.0/6.5	3.5P — 3.5RP	5.1 — 8.1	5.0P	4.9/6.3
5.0P	5.1/10.9	3.3P	5.3/12.3	7.3PB — 2.3RP	10.9 — 15.9	3.9P	5.0/8.7
5.5P	4.1/12.6	5.5P	4.2/13.2	1.5P — 1.5RP	10.4 — 16.4	5.0P	4.0/11 5
4.5P	6.9/2.7	8.8PB	8.0/1.4	6.7B — 0.5RP	0.6 — 2.6	4.9P	6.8/2 8
5.0P	7.1/4.8	1.0P	7.3/3.6	6.0B — 7.3P	2.9 — 3.9	5.2P	7.1/4.5
5.5P	7.0/6.4	2.3P	7.2/6.0	1.3PB — 1.3RP	4.6 — 7.6	5.6P	7.0/6.4
5.0P	6.1/9.1	1.0P	5.7/9.9	3.0PB — 8.0P	7.1 — 13.1	4.6P	6.1/8.6
4.5P	5.0/4.7	5.7P	4.4/5.7	2.8P — 2.8RP	4.0 — 9.0	4.8P	4.9/3.4
9.0P	3.0/9.8	6.0P	3.0/10.2	3.0P — 8.0P	7.8 — 12.8	7.9P	2.9/7.9
10.0P	3.2/4.5	7.0P	2.6/4.1	7.0PB — 7.0RP	2.1 — 5.1	7.5P	3.1/3.2
9.5P	7.3/6.0	3.3P	7.6/6.1	1.3PB — 1.3RP	5.3 — 7.3	9.5P	7.2/5.7
0.0RP	3.3/2.3	1.0RP	2.8/2.2	5.2PB — 2.7YR	1.0 — 5.0	5.3RP	2.2/1.5
4.0RP	2.4/5.9	8.3RP	3.1/7.7	7.0P — 8.2YR	6.1 — 11.1	2.7RP	2.3/3.8
5.0RP	3.2/8.4	7.0RP	3.1/9.4	4.0RP — 9.0RP	7.4 — 12.4	3.5RP	3.1/6.2
4.0RP	4.3/4.4	1.5RP	4.4/3.8	5.5P — 5.5RP	2.8 — 4.8	3.7RP	4.3/3.9
5.0RP	5.2/2.3	2.0R	5.7/2.3	3.0RP — 8.0R	1.7 — 3.7	5.2RP	5.1/2.2
4.5RP	5.1/6.2	2.0RP	5.1/6.0	7.0P — 7.0RP	5.2 — 7.2	4.3RP	5.1/5.7
5.0RP	4.3/10.7	6.5RP	4.3/11.5	2.5RP — 10.0RP	8.7 — 15.7	3.8RP	4.2/8.9
5.5RP	5.3/9.7	7.3RP	5.4/9.3	4.3RP — 9.3RP	7.1 — 11.1	4.6RP	5.3/8.6
4.5RP	6.3/8.5	3.0RP	6.5/8.2	9.5P — 4.5RP	5.8 — 10.8	3.9RP	6.3/7.7
6.5RP	7.3/2.3	5.3RP	8.2/1.9	10.0P — 8.7RP	1.1 — 2.6	6.4RP	7.3/2.2
5.5RP	8.1/2.8	7.5RP	5.4/2.4	3.5RP — 6.0R	1.9 — 3.4	5.3RP	8.1/2.7
4.5RP	7.4/4.9	3.5RP	7.9/5.2	3.3RP — 4.5RP	2.9 — 6.9	4.1RP	7.3/4.8
8.5RP	3.2/8.5	8.5RP	3.4/8.3	6.5RP — 1.5R	7.1 — 11.1	8.3RP	3.1/6.2
10.0RP	5.3/4.2	9.1RP	5.4/3.5	3.3RP — 7.0 R	2.3 — 3.8	9.2RP	5.3/3.9
9.0RP	7.1/5.8	0.8R	7.8/5.1	7.8RP — 1.5R	3.2 — 6.7	9.0RP	7.0/5.2

reddish-yellow to yellow, or from green-yellow green to yellowish green, each of which involves a change of 2.50 in the Munsell scale. Note that the observers were trained to report only within 2.50 Munsell hue steps. The greatest change from daylight is found with the lowest color temperature source 3500K, where the average hue change is over twice that found for either of the other two sources.

The differences among observers which appear in the inter-observer range of estimates in Tables II, III and IV are in line with what is known about individual differences in color vision from many types of study and are only in part due to the method of report employed in this investigation. Observers differ in the amounts of red, green and blue light necessary to produce white as well as in matching the chromatic gamut of colors. Colorimetric studies of the effects of adaptation as well as matches made while viewing samples under different sources of illumination either alternately or simultaneously reveal individual differences in the effects of chromatic adaptation of the sort found here. Thus 5.0R 4.2/12.8 in 6500K fluorescent illumination is reported as 3.5R (slightly on the bluish side) by one extreme observer and 7.3R (slightly

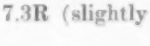


Figure 4. Approximate range (maximum among individual observers) of changes in color appearance from daylight to fluorescent sources (earlier type lamps).

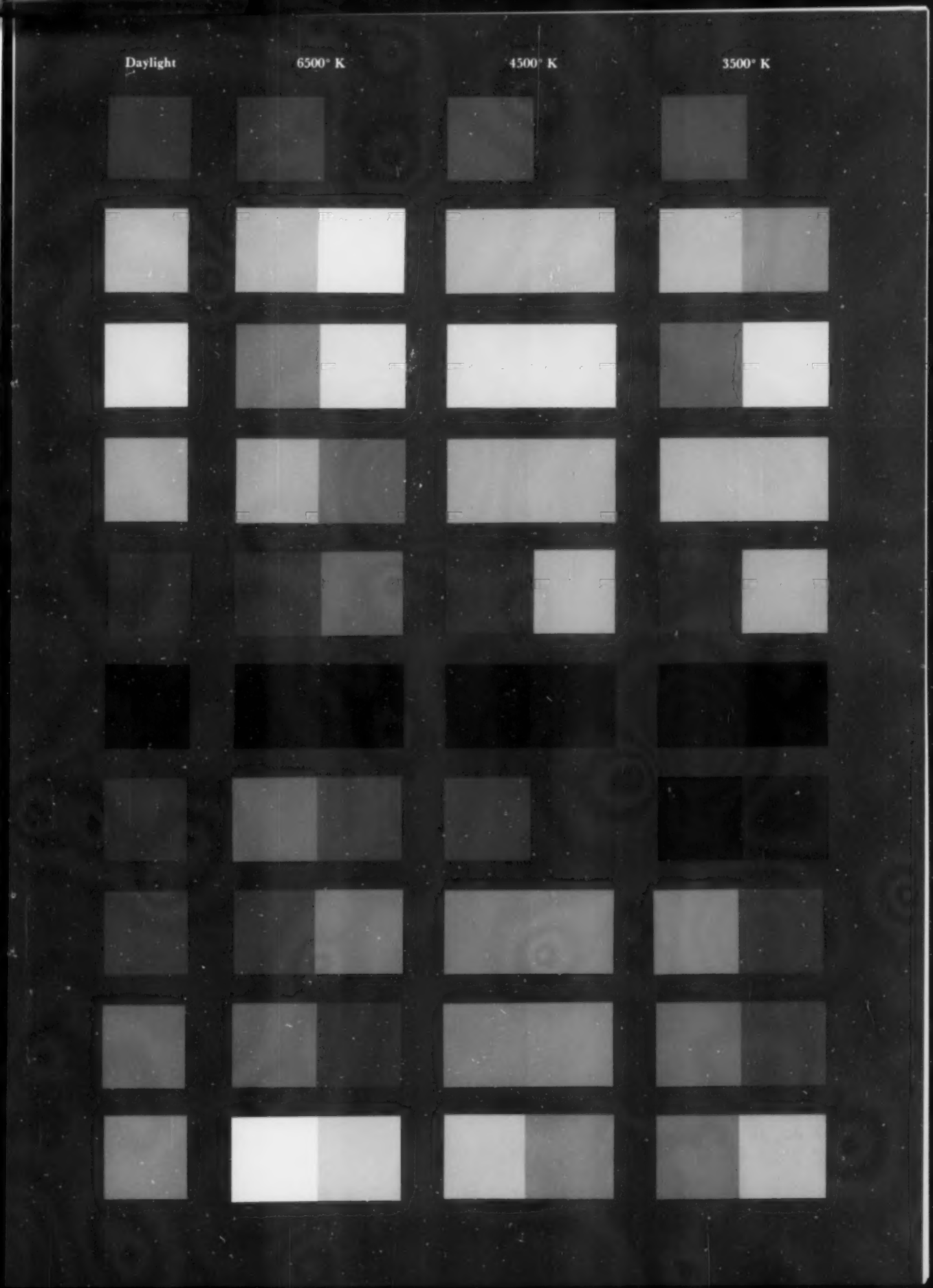

Daylight
6500° K
4500° K
3500° K

TABLE III — Observed and Computed Hue, Lightness and Saturation, and Observers' Range under 4500K Fluorescent Illumination.

Munsell Renotation		Observed		Observers' Range		Computed	
H	V/C	H	L/S	H	S	H	L/S
3.5R	2.3/2.2	6.3R	2.8/3.4	9.8RP — 8.5YR	1.0 — 8.0	3.3R	2.3/1.5
3.0R	2.5/4.8	5.5R	2.5/5.1	7.0RP — 0.7YR	3.9 — 6.9	2.7R	2.5/3.3
5.0R	3.3/7.4	4.2R	3.3/8.4	3.7R — 6.2R	5.8 — 12.8	4.8R	3.2/5.6
4.0R	5.0/2.8	5.0R	5.0/2.9	1.3R — 7.5R	2.1 — 4.1	4.5R	5.0/2.5
3.5R	4.1/4.7	0.5R	4.5/4.6	8.0RP — 5.5R	4.2 — 6.2	4.1R	4.1/4.1
4.0R	4.9/5.3	6.5R	4.6/6.8	8.5RP — 2.2YR	4.8 — 10.8	5.0R	5.0/4.9
5.0R	4.2/12.6	4.0R	4.0/14.4	3.5R — 6.0R	8.8 — 17.8	5.5R	4.2/11.0
5.5R	5.0/12.8	6.0R	4.4/13.0	4.0R — 6.5R	8.8 — 15.8	5.6R	5.1/11.2
2.5R	7.2/2.6	10.0RP	7.2/1.9	4.8RP — 3.5R	1.1 — 3.1	3.7R	7.2/2.4
3.5R	8.0/3.6	6.0R	8.2/3.3	1.5R — 1.5YR	1.6 — 4.6	5.0R	8.0/3.1
3.0R	7.1/5.2	3.8R	8.3/4.6	6.8RP — 5.5R	2.6 — 6.6	4.0R	7.1/4.5
3.5R	7.0/7.0	6.0R	7.2/8.4	3.2R — 0.7YR	7.2 — 10.2	4.2R	7.1/6.4
10.0R	3.3/5.4	1.0YR	3.4/7.4	9.0R — 4.0YR	6.2 — 11.2	0.8YR	3.3/4.0
9.5R	5.1/4.9	8.0R	5.4/4.2	4.5R — 2.0YR	3.6 — 5.1	1.0YR	5.1/4.4
0.5YR	6.2/10.1	2.5YR	6.2/11.5	9.0R — 4.0YR	7.5 — 16.5	2.0YR	6.4/9.3
4.5YR	2.4/1.8	6.5YR	2.6/2.2	7.5R — 7.5GY	0.4 — 6.6	4.6YR	2.4/1.2
5.0YR	3.3/4.1	8.5YR	3.0/5.2	4.5YR — 7.0Y	4.4 — 7.4	7.3YR	3.3/2.9
4.0YR	4.9/2.1	3.5YR	5.0/1.3	9.5R — 7.0YR	0.6 — 2.1	5.0YR	5.0/1.8
4.5YR	4.9/4.6	6.0YR	4.6/4.4	3.0YR — 0.5Y	3.6 — 5.6	5.8YR	5.0/4.0
5.5YR	5.1/9.0	4.5YR	5.9/10.6	10.0R — 7.5YR	7.4 — 15.4	6.9YR	5.2/7.7
3.0YR	7.0/2.1	6.0YR	7.1/1.9	10.0R — 10.0Y	1.2 — 2.2	5.0YR	7.1/2.0
4.0YR	8.0/3.5	1.5YR	8.3/3.6	8.5R — 6.0YR	1.9 — 6.9	5.9YR	8.1/3.0
3.5YR	6.9/5.9	4.0YR	7.2/5.4	9.5R — 7.0YR	2.9 — 11.9	5.0YR	7.0/5.5
4.5YR	7.0/8.2	8.0YR	7.2/6.9	5.5YR — 3.0Y	4.6 — 9.1	6.2YR	7.2/7.5
5.5YR	6.9/10.1	6.5YR	7.4/10.5	5.0YR — 7.5YR	7.9 — 13.9	7.0YR	7.1/9.2
6.0YR	6.2/11.5	7.0YR	6.0/10.9	5.0YR — 10.0YR	7.7 — 13.7	7.4YR	6.3/10.0
10.0YR	4.2/4.6	1.0Y	4.2/4.9	6.0YR — 3.5Y	4.3 — 6.3	1.6Y	4.3/3.9
10.0YR	5.1/4.4	4.5Y	5.2/4.3	9.5YR — 9.5Y	3.8 — 5.3	1.9Y	5.2/3.8
10.0YR	6.5/9.8	2.5Y	6.1/11.7	1.0Y — 6.0Y	7.7 — 14.7	2.4Y	6.6/8.8
5.0Y	2.5/1.4	3.5Y	2.3/1.1	8.5YR — 6.0GY	0.4 — 3.6	6.3Y	2.5/1.0
4.5Y	5.2/1.7	5.0Y	4.7/1.9	4.5Y — 7.0Y	1.3 — 2.3	7.3Y	5.2/1.6
5.0Y	4.1/3.6	8.5Y	4.1/3.9	4.5Y — 4.5GY	2.5 — 5.5	7.8Y	4.1/3.2
6.0Y	5.0/6.0	7.5Y	5.2/6.9	9.5YR — 2.0GY	5.3 — 11.3	8.6Y	5.1/5.4
3.5Y	7.8/1.6	2.5Y	7.6/2.1	6.5R — 6.5Y	1.4 — 3.4	6.3Y	7.8/1.6
4.5Y	7.9/5.8	5.5Y	7.7/6.4	5.0Y — 7.5Y	3.6 — 8.6	7.9Y	8.0/5.6
5.5Y	7.9/12.3	8.0Y	8.1/11.7	5.0Y — 10.0Y	8.7 — 15.7	9.2Y	8.1/11.5
5.5Y	7.9/8.3	5.5Y	7.7/9.9	3.5Y — 6.0Y	6.7 — 12.7	8.1Y	8.0/7.9
0.5GY	3.3/1.8	0.5GY	2.8/2.2	3.5Y — 6.0GY	1.3 — 4.3	1.8GY	3.3/1.6
10.0Y	4.3/3.7	3.5GY	4.3/4.0	7.0Y — 7.0GY	2.4 — 4.4	2.2GY	4.3/3.5
0.5GY	8.1/9.1	1.0GY	8.1/12.7	8.0Y — 3.0GY	7.7 — 15.7	2.3GY	8.2/9.1
5.5GY	2.5/2.2	2.0GY	2.1/2.0	4.0Y — 9.0GY	0.6 — 5.6	6.3GY	2.4/1.7
5.0GY	5.1/2.0	4.5GY	4.5/1.9	2.5Y — 10.0GY	1.3 — 3.3	6.1GY	5.2/2.0
5.0GY	5.1/5.4	5.5GY	5.1/5.6	1.5GY — 9.0GY	1.9 — 10.4	6.5GY	5.2/5.4
5.0GY	5.1/7.1	7.0GY	4.7/7.9	3.5GY — 1.0G	4.7 — 12.7	6.5GY	5.2/7.0
5.5GY	7.0/1.8	9.0GY	6.6/1.6	5.5GY — 5.5G	1.4 — 2.4	6.4GY	7.0/1.8
4.0GY	7.0/9.5	8.0GY	6.7/10.9	5.5GY — 3.0G	8.5 — 13.5	5.7GY	7.0/9.7
5.0GY	7.1/6.4	9.5GY	7.5/6.9	4.0GY — 6.5G	4.7 — 9.7	6.1GY	7.2/6.8
6.0GY	8.1/3.6	6.0GY	8.5/3.4	7.0Y — 4.5G	1.9 — 4.4	6.5GY	8.0/3.8
4.5GY	8.1/8.7	7.0GY	8.1/7.4	5.0GY — 5.0G	4.6 — 12.6	5.8GY	8.1/8.9
10.0GY	4.2/5.4	0.5G	3.9/6.2	8.0GY — 3.0G	4.0 — 10.0	0.7G	4.2/5.0
10.0GY	5.1/4.3	0.5G	5.2/5.0	8.5GY — 3.5G	3.1 — 6.6	0.2G	5.0/4.2
10.0GY	7.1/6.5	2.0G	7.0/8.1	6.5GY — 4.0G	5.2 — 10.2	0.7G	7.1/6.7
7.0G	2.2/2.4	8.5G	2.3/2.7	8.5G — 8.5G	0.1 — 4.1	8.5G	2.1/1.5
4.0G	3.3/4.8	4.5G	3.0/4.4	2.5G — 5.0G	3.2 — 5.2	5.0G	3.2/3.8
6.5G	4.9/2.4	0.7BG	5.1/2.8	1.2G — 6.2B	1.6 — 4.6	6.5G	4.9/2.2
5.0G	4.9/4.8	3.3G	5.0/5.2	0.5G — 6.8G	3.2 — 7.2	5.3G	4.8/4.4
5.0G	4.9/8.2	4.5G	5.7/9.6	1.0G — 6.0G	6.6 — 13.6	5.3G	4.8/7.3
6.5G	7.0/2.1	3.0G	7.5/1.8	3.0GY — 8.0BG	0.9 — 2.4	6.3G	6.9/2.1
7.0G	7.0/6.1	8.0G	6.8/7.0	7.7GY — 4.0BG	6.2 — 9.2	7.1G	7.0/6.0
6.0G	8.7/2.7	2.5G	8.9/2.6	7.5GY — 5.0BG	2.2 — 2.7	6.3G	8.6/2.3
10.0G	3.2/4.7	1.7BG	3.2/5.1	9.2G — 8.0BG	4.3 — 6.3	1.0BG	3.1/3.5
0.5BG	4.1/4.5	0.7BG	3.6/3.1	8.2G — 7.0BG	2.9 — 3.9	1.0BG	4.0/3.7
1.0BG	6.4/6.0	1.8BG	6.9/5.4	5.5G — 6.8BG	3.2 — 9.2	0.8BG	6.3/5.4
4.5BG	2.2/2.5	4.5BG	2.4/2.7	3.0BG — 6.8BG	0.9 — 4.9	7.1BG	2.1/1.4
5.0BG	2.3/3.7	4.5BG	2.3/3.7	3.0BG — 6.8BG	2.9 — 4.9	7.9BG	2.1/1.9
5.5BG	4.3/2.5	8.0BG	4.2/2.5	3.0BG — 1.7B	0.5 — 3.5	5.9BG	4.2/2.1
5.5BG	4.3/4.0	2.5B	4.4/3.7	4.3BG — 0.5PB	1.7 — 4.7	6.6BG	4.2/3.2
5.0BG	5.1/6.4	2.5BG	5.2/7.6	5.7G — 8.2BG	5.7 — 12.7	6.5BG	5.0/5.5
2.0BG	6.4/4.5	2.5BG	7.1/3.6	3.7G — 8.7BG	1.9 — 4.4	2.6BG	6.2/4.0
3.5BG	7.3/2.1	8.5BG	8.0/2.0	1.0G — 6.0B	1.3 — 3.3	1.6BG	7.2/2.0
4.5BG	7.2/3.4	0.2BG	7.2/3.0	7.2GY — 9.7BG	2.0 — 5.0	5.1BG	7.1/3.1
4.5BG	5.1/2.5	5.3BG	5.0/2.4	4.0G — 1.5B	1.8 — 2.8	5.5BG	5.1/2.2
9.5BG	3.2/5.8	3.0B	3.0/5.2	8.0BG — 4.2B	2.8 — 9.8	2.4B	3.0/3.8
9.5BG	4.1/4.0	9.0BG	4.2/4.4	3.0BG — 4.2B	3.2 — 6.2	1.6B	4.0/3.1
10.0BG	6.3/5.8	8.0BG	6.3/5.2	5.0BG — 2.5B	3.6 — 6.6	1.5B	6.1/5.1
2.0B	2.2/2.2	6.5B	2.4/2.0	3.2BG — 5.7PB	0.4 — 4.6	7.4B	2.1/1.2
5.0B	3.1/2.3	4.0B	3.3/2.0	2.0B — 7.0B	1.8 — 2.8	8.9B	3.1/1.8
6.5B	4.9/2.6	7.0B	5.2/2.0	5.0B — 10.0B	1.4 — 2.9	9.3B	4.9/2.5
5.5B	5.0/5.1	4.0B	5.0/5.3	6.5BG — 6.5B	4.5 — 6.5	7.8B	4.8/4.5
6.5B	4.0/6.9	5.2B	4.4/8.3	4.2B — 6.7B	6.7 — 12.7	0.2PB	3.7/5.7

(Table III continued on next page.)

TABLE III *(Continued)*.

Munsell Renotation		Observed		Observers' Range		Computed	
H	V C	H	L/S	H	S	H	L/S
5.0B	5.0/6.8	4.0B	4.5/8.0	9.0BG — 6.5B	5.5 — 12.5	7.7B	4.7/5.9
5.5B	6.1/6.4	3.5B	6.1/5.2	4.5BG — 7.0B	3.8 — 7.8	7.5B	5.9/5.9
4.0B	8.2/2.2	4.0B	8.0/1.6	6.0BG — 6.0B	1.3 — 1.8	5.0B	8.1/2.2
5.0B	7.1/4.7	5.0B	7.5/4.2	3.0B — 5.5B	1.9 — 5.9	7.5B	7.0/4.5
9.5B	3.2/5.6	9.0B	2.7/6.7	5.0B — 2.5PB	4.5 — 10.5	2.9PB	3.0/4.6
0.5PB	4.2/4.1	8.5B	3.7/3.8	2.5B — 10.0B	1.6 — 4.6	2.9PB	4.0/3.6
9.5B	7.2/5.7	8.5B	7.6/5.5	8.5B — 8.5B	3.9 — 6.9	1.9PB	7.0/5.5
4.5PB	2.2/2.6	4.5PB	2.4/3.2	4.5PB — 4.5PB	1.9 — 5.9	6.3PB	2.1/1.8
4.0PB	2.3/5.9	2.5PB	2.2/6.7	2.0PB — 4.5PB	4.3 — 10.3	3.3PB	2.1/4.6
4.0PB	3.3/9.4	4.0PB	2.7/8.2	3.5PB — 6.0PB	4.8 — 10.8	6.4PB	3.0/8.0
5.0PB	4.2/4.3	5.8PB	4.1/4.4	5.0PB — 8.8PB	3.6 — 5.6	6.4PB	4.1/4.2
5.0PB	5.1/3.1	5.5PB	5.1/2.7	4.2PB — 0.5P	2.3 — 3.3	6.3PB	5.1/3.1
4.0PB	5.3/6.2	5.5PB	5.6/6.6	2.0PB — 8.3PB	5.0 — 9.0	5.9PB	5.1/5.9
3.5PB	5.3/8.6	3.0PB	5.3/8.0	2.0PB — 4.5PB	6.6 — 10.6	5.7PB	5.1/8.5
5.0PB	8.3/3.2	6.8PB	8.6/2.8	5.9B — 7.2RP	1.8 — 3.8	6.9PB	8.2/3.3
4.0PB	7.2/5.6	5.3PB	7.5/4.8	2.5PB — 8.8PB	3.0 — 7.0	5.9PB	7.1/6.0
5.0PB	6.3/7.4	6.0PB	5.8/6.4	6.0PB — 6.0PB	4.2 — 8.2	5.9PB	6.1/6.6
10.0PB	2.2/5.5	1.5P	2.2/7.2	7.2PB — 6.0P	5.4 — 8.4	1.4P	2.1/3.9
10.0PB	4.1/4.6	8.5PB	3.9/3.1	6.0PB — 4.8P	1.6 — 4.6	1.3P	4.1/4.5
10.0PB	7.0/5.3	4.9P	7.2/5.3	0.9P — 0.9RP	3.2 — 8.2	1.6P	7.0/5.7
5.5P	2.1/2.9	8.2P	2.3/3.8	1.2P — 5.0RP	2.2 — 5.7	6.0P	2.1/2.1
5.0P	2.2/4.6	3.3P	2.6/5.8	6.2PB — 10.0P	4.4 — 6.9	5.0P	2.1/3.3
5.0P	3.3/11.2	6.0P	3.7/13.8	9.0PB — 9.0RP	10.2 — 16.2	5.0P	3.1/9.7
5.0P	5.0/2.5	6.0P	4.7/1.6	10.0PB — 10.0P	0.8 — 2.3	5.6P	5.0/2.7
5.0P	5.0/6.8	8.5P	5.2/7.1	8.5PB — 8.5RP	6.1 — 8.1	5.6P	4.9/6.7
5.0P	5.1/10.9	3.3P	4.9/12.7	2.3P — 7.3P	10.9 — 16.9	5.4P	5.0/11.1
5.5P	4.1/12.6	1.5RP	4.6/13.4	1.5P — 6.5RP	11.4 — 16.4	5.6P	4.0/12.2
4.5P	6.9/2.7	0.8P	7.7/1.8	6.7B — 5.5RP	0.6 — 2.6	5.5P	6.8/3.0
5.0P	7.1/4.8	7.3P	7.3/5.5	2.3P — 2.3RP	3.4 — 10.9	5.6P	7.1/5.9
5.5P	7.0/6.4	9.3P	7.0/6.8	1.3P — 1.3RP	5.6 — 10.6	6.1P	7.0/6.9
5.0P	6.1/9.1	5.0P	6.1/10.1	8.0PB — 3.0RP	8.1 — 14.1	5.5P	6.1/9.2
4.5P	5.0/4.7	7.7P	4.4/6.2	7.8P3 — 7.8RP	5.0 — 7.0	5.4P	4.9/4.8
9.0P	3.0/9.8	4.3P	2.8/10.2	9.2B — 3.0RP	5.8 — 12.8	8.3P	3.0/7.9
10.0P	3.2/4.5	7.0P	3.1/4.3	7.0PB — 7.0RP	2.1 — 7.1	0.2RP	3.1/3.6
9.5P	7.3/6.0	7.3P	7.3/6.7	1.3P — 1.3RP	5.3 — 8.3	10.0P	7.3/6.2
6.0RP	2.3/2.3	1.7R	2.7/2.4	9.0P — 2.7YR	1.0 — 5.0	5.8RP	2.2/1.6
4.0RP	2.4/5.9	7.0RP	2.9/7.5	2.0P — 7.0R	5.1 — 11.1	3.0RP	2.4/4.1
5.0RP	3.2/8.4	6.0RP	3.2/8.4	9.0P — 9.0RP	6.4 — 11.4	4.1RP	3.1/6.1
4.0RP	4.3/4.4	5.5RP	4.2/4.6	0.5RP — 0.5R	3.8 — 5.8	4.0RP	4.3/4.1
5.0RP	5.2/2.3	1.0R	5.8/2.3	3.0RP — 8.0R	1.7 — 3.7	5.5RP	5.2/2.3
4.5RP	5.1/6.2	3.0RP	4.8/5.2	7.0P — 7.0RP	4.2 — 6.2	4.3RP	5.2/6.0
5.0RP	4.3/10.7	5.5RP	4.4/10.9	2.5RP — 10.0RP	8.7 — 12.7	4.0RP	4.3/9.5
5.5RP	5.3/9.7	7.0RP	5.4/9.9	4.3RP — 0.5R	8.1 — 13.1	5.3RP	5.3/8.9
4.5RP	6.3/8.5	3.5RP	6.6/7.8	9.5P — 8.2RP	5.8 — 8.8	4.5RP	6.3/8.2
6.5RP	7.3/2.3	2.5RP	7.7/2.1	5.0P — 6.2RP	1.6 — 3.1	5.9RP	7.3/2.1
5.5RP	8.1/2.8	1.0RP	7.7/3.1	7.3PB — 6.0RP	1.9 — 4.9	6.3RP	8.1/2.7
4.5RP	7.4/4.9	3.2RP	7.9/5.8	8.3P — 5.2RP	4.9 — 6.4	4.7RP	7.4/4.9
8.5RP	3.2/8.5	7.7RP	3.5/9.7	6.5RP — 2.7R	7.1 — 11.1	7.5RP	3.1/6.4
10.0RP	5.3/4.2	7.3RP	4.8/4.3	3.3RP — 2.0R	2.8 — 5.8	0.1R	5.3/3.9
9.0RP	7.1/5.8	8.3RP	7.7/6.0	2.8RP — 1.5R	4.2 — 7.2	9.9RP	7.1/5.4

on the yellowish side) by another extreme observer while the average estimate is 4.8R. This type of result has also been found with a daylight source (Helson, 1939). The range of hues reported by the five observers for the 130 samples used in this study is no greater than has been found previously both with incandescent lamp light and daylight sources. Fig. 4 is a reproduction in color of 10 of these 130 samples as judged by the average observer and by the two extreme observers in each of the fluorescent sources.

The small hue changes found in this study make it appear that the differences between fluorescent and daylight illumination commonly reported must be sought in something other than color changes of single objects unless these objects are very familiar (such as complexions and foods). In the latter case even small changes in hue may influence consumer acceptance of light sources. Various comments from observers apart from their reports of specific colors reveal that they recognized the fluorescent illumination was different from "normal daylight." Thus one observer reported that "Everything looks distorted in some way but I can't tell just how"; another reported that "All the samples seem to fluoresce"; and still another: "The samples glow — it's like looking at a powdery pastel." Sometimes the change in hue could not be adequately described in conventional terms as in the following report: "This sample looks like a red gone wrong." Small hue changes in many samples coupled with unusual appearance of well-known colors may cumulate to produce an over-all unfavorable impression of the quality of illumination. Whether or not the total effect is acceptable must be determined by aesthetic studies beyond the scope of an investigation concerned with the color-rendering properties of sources of illumination.

TABLE IV — Observed and Computed Hue, Lightness and Saturation, and Observers' Range Under 3500K Fluorescent Illumination.

Munsell Renotation		Observed		Observers' Range		Computed	
H	V/C	H	L/S	H	S	H	L/S
3.5R	2.3/2.2	0.8YR	2.3/3.5	9.8RP — 3.5YR	3.0 — 4.0	4.0R	2.3/1.5
3.0R	2.5/4.8	1.3R	2.4/5.0	7.0RP — 5.7R	3.9 — 5.9	3.1R	2.5/3.4
5.0R	3.2/7.4	6.2R	3.4/7.8	3.7R — 8.7R	5.8 — 12.8	5.2R	3.3/5.9
4.0R	5.0/2.8	10.0R	5.6/2.5	7.5R — 5.0YR	1.1 — 4.1	5.4R	5.1/2.6
3.5R	4.1/4.7	3.5R	4.5/4.2	0.5R — 5.5R	2.2 — 5.2	5.0R	4.2/4.1
4.0R	4.9/5.3	7.0R	4.6/6.7	8.5RP — 2.2YR	5.8 — 9.8	5.4R	5.1/5.4
5.0R	4.2/12.6	4.5R	4.1/15.4	3.5R — 6.0R	11.8 — 17.8	5.9R	4.3/11.3
5.5R	5.0/12.8	6.5R	6.1/13.1	4.0R — 4.0YR	9.3 — 15.8	5.8R	5.2/11.5
2.5R	7.2/2.6	1.8R	7.6/2.9	9.8RP — 6.0R	2.1 — 4.1	5.5R	7.2/2.4
3.5R	8.0/3.6	6.5R	9.1/3.8	1.5R — 4.0YR	2.6 — 5.6	5.5R	8.1/3.0
3.0R	7.1/5.2	6.3R	7.9/5.1	1.8R — 0.5YR	2.6 — 8.6	4.9R	7.2/4.6
3.5R	7.0/7.0	8.7R	6.5/9.2	3.2R — 3.2YR	7.2 — 11.2	5.0R	7.1/6.4
10.0R	3.3/5.4	10.0R	3.2/6.4	9.0R — 1.5YR	5.2 — 8.2	1.0YR	3.4/4.2
9.5R	5.1/4.9	0.5YR	5.5/4.1	9.5R — 2.0YR	2.1 — 6.1	3.0YR	5.2/4.2
0.5YR	6.2/10.1	4.0YR	6.6/12.3	1.5YR — 6.5YR	9.5 — 14.5	2.1YR	6.5/8.8
4.5YR	2.4/1.8	1.0YR	2.5/2.4	7.5R — 2.5YR	1.6 — 3.6	5.8YR	2.4/1.2
5.0YR	3.3/4.1	5.5YR	2.9/4.6	4.5YR — 9.5YR	2.4 — 7.4	7.3YR	3.4/3.2
4.0YR	4.9/2.1	8.5YR	5.3/1.8	4.5YR — 7.0Y	1.1 — 3.1	7.5YR	5.0/1.8
4.5YR	4.9/4.6	4.0YR	5.2/4.5	3.0YR — 5.5YR	4.1 — 4.6	5.1YR	5.1/4.0
5.5YR	5.1/9.0	4.5YR	4.4/8.0	2.5YR — 7.5YR	3.4 — 12.4	8.3YR	5.3/7.7
3.0YR	7.0/2.1	9.5YR	8.5/2.3	10.0R — 10.0Y	1.2 — 3.2	6.3YR	7.1/1.9
4.0YR	8.0/3.5	4.0YR	8.1/2.8	1.0YR — 1.0Y	1.9 — 4.9	7.4YR	8.2/3.2
3.5YR	6.9/5.9	3.5YR	7.6/4.9	2.0YR — 4.5YR	3.9 — 5.9	6.1YR	7.1/5.6
4.5YR	7.0/8.2	8.0YR	8.6/8.4	3.0YR — 0.5Y	7.6 — 10.6	7.5YR	7.3/7.6
5.5YR	6.9/10.1	8.5YR	6.5/11.7	5.0YR — 2.5Y	8.9 — 14.9	8.3YR	7.2/9.2
6.0YR	6.2/11.5	5.5YR	5.9/11.1	2.5YR — 10.0YR	6.7 — 15.7	8.2YR	6.5/10.1
10.0YR	4.2/4.6	1.5Y	4.1/4.5	8.5YR — 6.0Y	3.3 — 6.3	3.7Y	4.3/3.9
10.0YR	5.1/4.4	2.5Y	5.4/3.6	4.5YR — 9.5Y	2.8 — 4.8	3.4Y	5.2/3.8
10.0YR	6.5/9.8	3.8Y	6.0/9.9	2.3Y — 6.0Y	7.7 — 14.7	3.8Y	6.8/8.9
5.0Y	2.5/1.4	1.5Y	2.3/1.5	6.0YR — 1.0GY	0.6 — 2.6	7.3Y	2.5/1.1
4.5Y	5.2/1.7	1.5GY	4.7/2.8	4.5Y — 2.0G	2.3 — 4.3	9.4Y	5.2/1.7
5.0Y	4.1/3.6	5.5Y	3.5/3.7	7.0YR — 7.0GY	1.5 — 8.5	10.0Y	4.2/3.4
6.0Y	5.0/6.0	5.0GY	5.1/7.7	2.0GY — 9.5GY	7.3 — 9.3	0.6GY	5.2/5.6
3.5Y	7.8/1.6	5.5Y	7.3/2.8	4.0Y — 6.5Y	1.4 — 6.4	8.7Y	7.8/1.6
4.5Y	7.9/5.8	4.5Y	8.7/7.4	2.5Y — 5.0Y	3.6 — 13.6	0.3GY	8.1/5.7
5.5Y	7.9/12.3	8.5Y	7.9/11.9	7.5Y — 10.0Y	8.7 — 16.7	1.1GY	8.2/11.5
5.5Y	7.9/8.3	6.0Y	7.6/11.7	6.0Y — 6.0Y	7.7 — 15.7	9.9Y	8.1/8.0
0.5GY	3.3/1.8	4.5GY	2.6/1.6	6.0Y — 9.8G	0.3 — 3.3	3.5GY	3.3/1.8
10.0Y	4.3/3.7	4.5GY	3.7/3.8	2.0GY — 7.0GY	2.4 — 5.4	4.1GY	4.3/3.7
0.5GY	8.1/9.1	4.0GY	8.3/11.3	0.5GY — 3.0G	7.7 — 15.7	3.9GY	8.2/9.4
5.5GY	2.5/2.2	4.0GY	2.3/2.0	9.0Y — 6.5GY	1.1 — 2.6	7.0GY	2.4/1.6
5.0GY	5.1/2.0	4.5GY	5.1/2.2	5.0Y — 7.5GY	1.3 — 3.3	7.0GY	5.1/2.2
5.0GY	5.1/5.4	8.0GY	4.7/6.0	6.5GY — 9.0GY	2.4 — 9.4	7.5GY	5.2/6.0
5.0GY	5.1/7.1	7.0GY	4.8/9.3	1.0GY — 8.5GY	4.7 — 13.7	7.5GY	5.2/7.6
5.5GY	7.0/1.8	8.5Y	8.3/2.8	8.0Y — 0.5GY	1.4 — 6.4	7.0GY	7.0/1.9
4.0GY	7.0/9.5	8.0GY	6.9/10.1	5.5GY — 3.0G	6.5 — 12.5	6.6GY	7.1/10.4
5.0GY	7.1/6.4	7.5GY	6.7/7.9	4.0GY — 4.0G	4.7 — 9.7	7.0GY	7.2/7.2
6.0GY	8.1/3.6	2.0GY	9.2/4.3	9.5Y — 7.0GY	2.9 — 5.9	7.1GY	8.1/4.0
4.5GY	8.1/8.7	5.0GY	7.9/11.2	5.0GY — 5.0GY	5.6 — 14.6	6.4GY	8.1/9.4
10.0GY	4.2/5.4	1.0G	4.0/6.2	8.0GY — 3.0G	4.0 — 8.0	1.0G	4.1/5.5
10.0GY	5.0/4.3	0.5G	4.8/4.7	3.5GY — 3.5G	3.1 — 6.1	1.2G	5.0/4.6
10.0GY	7.1/6.5	10.0GY	7.5/8.4	4.0GY — 4.0G	6.2 — 10.2	1.4G	7.1/7.2
7.0G	2.2/2.4	10.0G	1.7/2.1	8.5G — 2.3BG	1.1 — 3.1	9.1G	2.1/1.5
4.0G	3.3/4.8	4.5G	3.4/4.0	2.5G — 5.0G	2.2 — 6.2	5.8G	3.1/3.8
6.5G	4.9/2.4	2.2BG	4.3/3.6	7.5G — 6.2BG	2.6 — 5.6	7.4G	4.8/2.3
5.0G	4.9/4.8	2.5G	5.6/4.8	0.5G — 3.0G	3.2 — 6.2	6.2G	4.7/4.6
5.0G	4.9/8.2	3.5G	4.6/10.2	1.0G — 6.0G	7.6 — 12.6	5.7G	4.6/7.3
6.5G	7.0/2.1	1.0G	8.0/2.3	0.5GY — 5.5BG	1.9 — 2.9	7.4G	6.9/2.2
7.0G	7.0/6.1	3.7G	7.6/6.4	0.2G — 5.2G	4.2 — 8.2	7.4G	6.9/6.2
8.0G	8.7/2.7	10.0GY	9.1/3.4	10.0YR — 2.5B	2.7 — 5.7	6.8G	8.6/2.4
10.0G	3.2/4.7	2.3BG	3.4/3.3	9.2G — 3.0BG	1.3 — 4.3	2.2BG	3.0/3.3
0.5BG	4.1/4.5	7.5G	3.5/3.1	5.7G — 2.0BG	1.9 — 4.9	2.0BG	4.0/3.8
1.0BG	6.4/6.0	3.3BG	6.8/5.4	5.5G — 0.5B	4.2 — 7.2	1.4BG	6.2/5.6
4.5BG	2.2/2.5	6.3BG	1.6/2.1	3.0BG — 1.8B	0.9 — 3.9	8.1BG	2.1/1.3
5.0BG	2.3/3.7	5.0BG	1.5/4.9	2.5BG — 1.3B	0.9 — 11.9	9.1BG	2.1/1.8
5.5BG	4.3/2.5	0.2B	3.6/2.3	1.7G — 9.2B	1.5 — 3.5	7.1BG	4.1/2.0
5.5BG	4.3/4.0	0.5B	3.8/4.3	0.5BG — 8.0B	2.7 — 6.7	7.1BG	4.1/3.2
5.0BG	5.1/6.4	4.2BG	5.3/7.3	9.5G — 8.2BG	6.7 — 8.7	7.6BG	4.8/5.2
2.0BG	6.4/4.5	3.5BG	7.1/4.0	3.7G — 3.7B	2.9 — 4.9	3.3BG	6.2/4.2
3.5BG	7.3/2.1	7.2BG	8.4/1.9	8.5GY — 6.0B	1.3 — 3.3	4.0BG	7.2/2.0
4.5BG	7.2/3.4	5.0BG	8.3/2.5	7.2GY — 7.2B	1.0 — 5.0	5.9BG	7.1/3.0
4.5BG	5.1/2.5	3.8BG	4.9/3.0	1.5G — 6.5B	1.8 — 3.8	6.0BG	5.0/2.3
9.5BG	3.2/5.8	4.2B	2.1/4.3	1.7B — 9.2B	1.8 — 7.8	4.9B	2.7/3.6
9.5BG	4.1/4.0	2.2B	4.3/3.6	9.2BG — 6.7B	3.2 — 4.2	2.8B	3.9/3.1
10.0BG	6.3/5.8	2.0B	6.6/7.0	5.0BG — 7.5B	4.6 — 10.6	2.5B	6.0/5.0
2.0B	2.2/2.2	9.5B	1.9/1.4	2.0B — 8.2PB	0.4 — 2.6	7.8B	2.1/1.4
5.0B	3.1/2.3	5.0B	2.4/0.9	2.0B — 7.0B	0.2 — 2.8	10.0B	3.0/1.8
6.5B	4.9/2.6	5.5B	5.2/1.9	2.5B — 7.5B	0.4 — 3.4	9.6B	4.8/2.5
5.5B	5.0/5.1	6.5B	4.4/4.3	4.0B — 9.0B	3.5 — 4.5	9.2B	4.7/4.5
6.5B	4.0/6.9	5.7B	3.6/6.9	1.7B — 9.2B	3.7 — 9.7	2.0PB	3.5/5.7

(Table IV continued on next page.)

TABLE IV *(Continued)*.

Munsell Renotation H	Munsell Renotation V/C	Observed H	Observed L/S	Observers' Range H	Observers' Range S	Computed H	Computed L/S
5.0B	5.0/6.8	6.5B	4.3/6.6	4.0B — 9.0B	5.6 — 7.6	9.6B	4.6/4.6
5.5B	6.1/6.4	6.0B	6.5/5.4	4.5B — 7.0B	3.8 — 7.8	9.2B	6.1/5.8
4.0B	8.2/2.3	4.0B	9.0/1.1	4.0B — 4.0B	0.8 — 1.8	6.2B	9.1/2.2
5.0B	7.1/4.7	4.0B	7.4/4.3	0.5B — 5.5B	2.9 — 6.9	8.5B	6.9/4.6
9.5B	3.2/5.6	0.5PB	2.7/6.7	7.5B — 2.5PB	3.5 — 8.5	4.7PB	2.9/4.7
0.5PB	4.2/4.1	1.0PB	3.5/4.0	10.0B — 2.5PB	2.6 — 4.6	3.9PB	4.0/3.8
9.5B	7.2/5.7	9.0B	8.5/3.9	8.5B — 1.0PB	2.9 — 4.9	2.5PB	6.9/5.6
4.5PB	2.2/2.6	3.5PB	1.4/2.9	9.5B — 4.5PB	1.9 — 4.9	7.5PB	2.0/1.8
4.0PB	3.3/5.9	3.0PB	1.1/4.4	2.0PB — 4.5PB	3.3 — 5.3	7.5PB	2.0/4.6
4.0PB	3.3/9.4	4.5PB	3.1/8.1	3.5PB — 6.0PB	5.3 — 10.8	7.5PB	2.9/8.6
5.0PB	4.2/4.3	4.8PB	3.9/3.4	2.5PB — 8.8PB	2.6 — 5.6	7.3PB	4.1/4.4
5.0PB	5.1/3.1	5.3PB	5.2/3.4	1.7PB — 8.0PB	2.3 — 4.3	7.5PB	5.0/3.1
4.0PB	5.3/6.2	6.8PB	5.1/6.2	2.0PB — 8.3P	5.0 — 8.0	7.1PB	5.1/6.3
3.5PB	5.3/8.6	3.0PB	5.4/8.8	2.0PB — 4.5PB	4.6 — 13.6	6.1PB	5.0/9.0
5.0PB	8.3/3.2	7.1PB	9.4/2.2	9.6B — 5.9P	1.8 — 2.8	7.3PB	8.1/3.4
4.0PB	7.2/5.6	8.3PB	7.3/6.0	5.0PB — 3.8P	4.0 — 8.0	7.0PB	7.0/5.8
5.0PB	6.3/7.4	6.3PB	5.5/6.4	3.5PB — 9.8PB	4.2 — 8.2	6.9PB	6.0/7.0
10.0PB	2.2/5.5	4.0P	2.6/6.4	1.0P — 1.0RP	5.4 — 9.4	2.0P	2.1/4.3
10.0PB	4.1/4.6	3.8P	4.1/4.8	9.8PB — 9.8P	2.6 — 6.6	2.1P	4.0/4.9
10.0PB	7.0/5.3	1.2RP	6.9/5.4	7.1PB — 5.9R	3.2 — 10.2	2.2P	6.9/5.8
5.5P	2.1/2.9	0.3RP	2.5/3.9	1.2P — 10.0RP	2.7 — 5.7	6.3P	2.1/2.3
5.0P	2.2/4.6	6.0P	2.3/6.6	10.0PB — 10.0P	4.9 — 8.9	5.4P	2.1/3.6
5.0P	3.3/11.2	1.0RP	3.4/13.0	4.0P — 9.0RP	10.2 — 15.2	5.7P	3.1/10.4
5.0P	5.0/2.5	2.0RP	5.4/1.8	10.0P — 10.0RP	1.3 — 2.3	6.4P	5.0/2.9
5.0P	5.0/6.8	4.5RP	5.1/7.5	8.5P — 8.5RP	7.1 — 8.1	6.3P	4.9/7.4
5.0P	5.1/10.9	6.3P	5.0/12.7	2.3P — 2.3RP	10.9 — 16.9	5.9P	5.0/11.8
5.5P	4.1/12.6	3.5RP	4.0/14.1	6.5P — 6.5RP	12.4 — 16.4	6.4P	4.0/13.3
4.5P	6.9/2.7	1.5RP	8.1/2.6	5.5P — 5.5RP	0.6 — 4.6	5.9P	6.8/3.1
5.0P	7.1/4.8	6.3P	7.5/5.5	2.3PB — 2.3RP	3.9 — 7.4	6.1P	7.0/5.2
5.5P	7.1/6.4	9.3P	8.3/6.0	1.3P — 1.3RP	4.6 — 7.6	8.3P	7.0/8.0
5.0P	6.1/9.1	9.0P	6.1/12.5	3.0P — 3.0RP	8.1 — 16.1	6.0P	6.0/9.9
4.5P	5.0/4.7	7.7P	3.8/6.2	2.8P — 2.8RP	5.0 — 8.0	6.1P	4.9/5.2
9.0P	3.0/9.8	9.0P	3.1/11.6	3.0P — 3.0RP	8.8 — 14.8	9.1P	2.9/8.6
10.0P	3.2/4.5	3.0RP	2.7/5.1	2.0P — 7.0RP	4.1 — 7.1	0.6RP	3.2/4.3
9.5P	7.3/6.0	5.3P	7.8/6.7	1.3P — 1.3RP	5.3 — 9.3	0.5RP	7.3/6.5
6.0RP	2.3/2.3	3.0R	2.6/2.4	4.0RP — 2.7YR	1.5 — 5.0	6.2RP	2.2/1.6
4.0RP	2.4/5.9	4.0RP	2.5/7.5	7.0P — 2.0R	7.1 — 8.1	3.4RP	2.4/4.4
5.0RP	3.2/8.4	7.0RP	2.8/9.0	9.0P — 9.0RP	6.4 — 11.4	4.4RP	3.2/7.0
4.0RP	4.3/4.4	4.5RP	4.6/3.5	5.5P — 0.5R	1.8 — 5.8	4.4RP	4.3/4.2
5.0RP	5.2/2.3	2.8R	5.6/2.3	8.0RP — 1.7YR	0.7 — 3.7	6.2RP	5.2/2.3
4.5RP	5.1/6.2	5.0RP	4.6/6.4	2.0RP — 7.0RP	5.2 — 8.2	5.2RP	5.2/6.3
5.0RP	4.3/10.7	3.0RP	4.3/12.3	5.0P — 5.0RP	8.7 — 16.7	4.7RP	4.3/9.9
5.5RP	5.3/9.7	8.3RP	6.5/9.1	4.3RP — 9.3RP	6.1 — 12.1	5.6RP	5.4/9.6
4.5RP	6.3/8.5	5.5RP	6.9/10.0	9.5P — 0.7R	8.8 — 12.8	4.8RP	6.4/8.7
6.5RP	7.3/2.3	2.8RP	8.6/2.4	10.0B — 8.7R	1.1 — 3.1	7.1RP	7.3/2.2
5.5RP	8.1/2.8	5.5RP	9.1/3.0	3.5RP — 6.0RP	1.9 — 4.4	6.3RP	8.1/2.9
4.5RP	7.4/4.9	6.3RP	8.1/6.5	3.3RP — 7.0RP	4.9 — 8.9	5.0RP	7.4/5.0
8.5RP	3.2/8.5	0.5R	3.4/8.4	6.5RP — 1.5R	6.1 — 11.1	7.9RP	3.2/6.8
10.0RP	5.3/4.2	7.0RP	5.0/3.8	3.3RP — 2.0R	2.8 — 4.8	0.9R	5.4/4.0
9.0RP	7.1/5.8	1.0R	8.3/6.1	9.0RP — 4.0R	3.2 — 9.2	10.0RP	7.2/5.5

Turning now to saturation we find from the summary in Table VI that, in general, the samples were estimated slightly more saturated in the fluorescent illuminants than in daylight as checked by observations under Macbeth daylight illumination (incandescent lamp plus Corning Daylite filter). The average observed gain in saturation as compared with daylight is 0.13 in 6500K, 0.25 in 4500K, and 0.33 in 3500K. Only two hues, green-yellow and purple in 3500K, change more than one Munsell chroma step on the average as shown in Table VI. In view of the large inter-observer variations when estimating saturation these small increases cannot be regarded as either practically important or statistically significant. Saturation can therefore be said to change very little from source to source within the limits of this study.

No extended discussion of lightness is necessary because of the excellent agreement between observed and theoretical estimates of this dimension, not only for the present study (Tables II, III and IV), but also in a previous study (Judd, 1940) providing a more severe test.

4. Theory

The chief purpose of the present investigation was to test whether or not a relatively simple quantitative formulation found adequate to predict the colors of objects seen under incandescent-filament sources of light (Helson, Judd, and Warren, 1952) would be adequate to predict the colors of objects seen under fluorescent sources of illumination. As in the previous paper, the theoretical computations were based on a three-components theory whose primaries are at the co-punctal points of the three types of dichromatic vision (protan-

TABLE V — Mean Hue Changes of 130 Munsell Samples in Passing from Daylight (Munsell Renotation) to Three Fluorescent Sources.

Daylight Munsell Renotation		Fluorescent Sources 6500°K	4500°K	3500°K
Red	Observed	0.32 yellower	0.59 yellower	2.07 yellower
	Calculated	0.09 bluer	0.65 yellower	1.35 yellower
Yellow-Red	Observed	0.14 bluer	1.43 yellower	1.45 yellower
	Calculated	0.46 yellower	1.58 yellower	2.91 yellower*
Yellow	Observed	0.86 greener	0.95 greener	2.75 greener
	Calculated	0.48 greener	2.48 greener*	4.39 greener
Green-Yellow	Observed	1.37 greener	1.25 greener	0.05 yellower
	Calculated	0.01 greener	0.91 greener	1.68 greener
Green	Observed	0.30 bluer	0.05 bluer	0.74 yellower
	Calculated	0.73 yellower	0.41 bluer	1.17 bluer
Blue-Green	Observed	1.08 bluer	0.75 bluer	2.10 bluer
	Calculated	0.02 yellower	1.28 bluer	2.45 bluer
Blue	Observed	0.92 greener	0.40 greener	0.76 redder
	Calculated	1.44 redder**	2.91 redder**	4.10 redder**
Purple-Blue	Observed	0.09 redder	0.76 redder	2.11 redder
	Calculated	0.86 redder	1.49 redder*	2.62 redder
Purple	Observed	1.71 bluer	0.32 redder	3.62 redder
	Calculated	0.54 bluer	0.29 redder	0.96 redder**
Red-Purple	Observed	0.27 redder	0.08 redder	1.14 redder
	Calculated	0.64 bluer	0.27 bluer	0.21 redder

*Difference between observation and theory statistically significant between 1% and 5% levels.
**Difference between observation and theory statistically significant at or beyond the 1% level.

opia, deuteranopia, tritanopia). The coordinate system based on these particular primaries may be defined by giving the connection between the tristimulus values, R, G, V, of any object color and the tristimulus values X, Y, Z (Y = luminous reflectance) of that color in the C.I.E. system, which is closely (Judd, 1944) the following:

$$\left.\begin{aligned} R &= 1.00Y \\ G &= -0.46X + 1.36Y + 0.10Z \\ V &= 1.00Z \end{aligned}\right\} \quad (1)$$

The reverse transformation is obtained by solving explicitly for X, Y, Z, in terms of R. G, V, thus:

$$\left.\begin{aligned} X &= 2.957R - 2.174G + 0.217V \\ Y &= 1.000R \\ Z &= 1.000V \end{aligned}\right\} \quad (1a)$$

It is assumed that the tristimulus values, R, G, V, also correspond to the responses of an observer adapted to C.I.E. source C (representative of average daylight). To find the red, green, and violet responses, R′, G′, V′, of an observer adapted to a source of some other chromaticity, the tristimulus values, G and V, are adjusted relative to the R-response to take account of the changed sensitivities of the red, green, and violet receptor mechanisms in accord with equation 2:

$$\left.\begin{aligned} R' &= (R_c/R_s)R \\ G' &= (G_c/G_s)G \\ V' &= (V_c/V_s)V \end{aligned}\right\} \quad (2)$$

where R_c, G_c, V_c are the tristimulus values of C.I.E. source C, and R_s, G_s, V_s those for the source being compared to it. From equation (1) the tristimulus values, X′, Y′, Z′, corresponding to R′,G′,V′, may be expressed in terms of the unadjusted tristimulus values X, Y, Z, as in equation 3:

$$\left.\begin{aligned} X' &= (G_c/G_s)X + 2.957(R_c/R_s - G_c/G_s)Y \\ &\quad + 0.217(V_c/V_s - G_c/G_s)Z \\ Y' &= (R_c/R_s)Y \\ Z' &= (V_c/V_s)Z \end{aligned}\right\} \quad (3)$$

TABLE VI — Mean Change in Saturation of 10 Munsell Major Hues from Daylight to Fluorescent Illumination.

Munsell Renotation (Daylight)	Fluorescent Sources 6500K Obs.	6500K Comp.	4500K Obs.	4500K Comp.	3500K Obs.	3500K Comp.
R	0.3	−0.9	0.6	−0.9	0.7	−0.8
YR	0.1	−0.7	0.1	−0.8	0.0	−0.7
Y	0.6	−0.5	0.7	−0.3	0.9	−0.2
GY	0.3	−0.3	0.3	0.0	1.0	0.3
G	−0.3	−0.8	0.1	−0.6	0.0	−0.5
BG	0.3	−0.8	−0.1	−0.8	0.0	−0.9
B	−0.1	−0.8	0.0	−0.6	−0.6	−0.7
PB	−0.2	−0.7	−0.1	−0.4	−0.2	−0.2
P	0.3	−0.9	0.7	−0.3	1.1	0.2
RP	0.0	−0.9	0.2	−0.7	0.4	−0.4
Average	0.13	−0.73	0.25	−0.54	0.33	−0.39

*This theory, with somewhat different primaries, was also found by Bouma and Kruithof (1947/1948) to be successful for the prediction of the hues of object-color perceptions both for the incandescent lamp as source, and for the low-pressure mercury lamp, which yields a discontinuous spectrum. They made no attempt to apply the theory to prediction of the saturations of object-color perceptions.

TABLE VII — Computations for Calculating Hue and Saturation of Munsell Sample 3.5R 2.3/2.2 in Three Fluorescent Illuminants.

Tristimulus values X	Y	Z	$Z'=2.343Z+.024$	$Y'=Y+.020$	$X'=1.093X-.275Y+.271Z+.020$	$X'+Y'+Z'$	x'	y'	z'
3500K Fluorescent									
0516	.0421	.0184	.0671	.0621	.0698	.1990	.351	.312	.337
4500K Fluorescent									
.0489	.0410	.0277	.0666	.0610	.0687	.1963	.350	.311	.339
6500K Fluorescent									
.0458	.0397	.0391	.0663	.0597	.0668	.1928	.346	.310	.344

The tristimulus values of source C and of the three fluorescent sources used in the observations (Nickerson and Wilson, 1950) are as follows:

	X	Y	Z
Source C	0.980	1.000	1.181
3500K fluorescent	1.021	1.000	0.504
4500K fluorescent	.988	1.000	0.768
6500K fluorescent	.952	1.000	1.091

The sensitivities of the green and violet receptor mechanisms for an observer adapted to one of the several sources studied relative to those for the observer adapted to an equal luminance of source C are found in accord with equation 2 as follows:

	R_c/R_s	G_c/G_s	V_c/V_s
C.I.E Source A (2854K)	1.000	1.154	3.327
3500K fluorescent	1.000	1.093	2.343
4500K fluorescent	1.000	1.046	1.538
6500K fluorescent	1.000	0.996	1.082
C.I.E. Source C (6740K)	1.000	1.000	1.000

It will be noted that the degrees of chromatic adaptation that formula 3 must take into account for the fluorescent sources are intermediate to that for source A, previously studied (Helson, Judd, Warren, 1952), and source C, taken as the standard for normal adaptation. In particular, the chromatic adjustment required for 6500K fluorescent is quite minor.

The tristimulus values, X′, Y′, Z′, corresponding to the responses adjusted for the changed sensitivities by this form of three-component theory may be found from equation 3 as follows:

3500K fluorescent

$$\left.\begin{aligned} X' &= 1.093X - 0.275Y + 0.271Z \\ Y' &= 1.000Y \\ Z' &= 2.343Z \end{aligned}\right\} \quad (3a)$$

4500K fluorescent

$$\left.\begin{aligned} X' &= 1.046X - 0.133Y + 0.107Z \\ Y' &= 1.000Y \\ Z' &= 1.538Z \end{aligned}\right\} \quad (3b)$$

6500K fluorescent

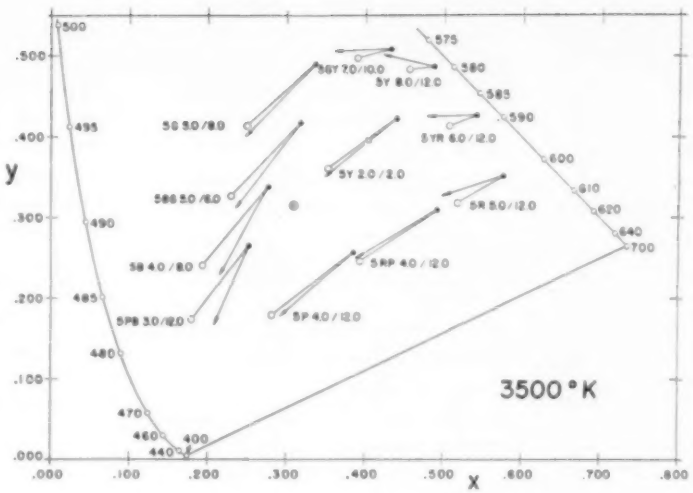
$$\left.\begin{aligned} X' &= 0.996X + 0.012Y + 0.019Z \\ Y' &= 1.000Y \\ Z' &= 1.082Z \end{aligned}\right\} \quad (3c)$$

To find the Munsell renotations of the colors corresponding to these adjusted responses it is only necessary to compute chromaticity coordinates (x′, y′) in the usual way for X′, Y′, Z′ and read the renotations by interpolation on the charts defining the ideal Munsell system (Newhall, Nickerson, Judd, 1943). We deemed it worthwhile, however, to depart from this simple theory by introducing three additive constants, $0.020X_c$, $0.020Y_c$, $0.020Z_c$ into the expressions for X′, Y′, Z′, respectively, given above. These constants were determined empirically from the results of the previous study (Helson, Judd, Warren, 1952) which showed that the simple theory predicted generally higher saturations (on average higher by 0.85 Munsell step) under source A than under source C, a prediction not borne out by the observations.

The method of calculating the hue and saturation to be expected of any sample under any source when its tristimulus values, X, Y, Z, for that source are known, according to the present formulation, is illustrated in Table VII wherein the theoretical X′, Y′, Z′ for samples in the three given sources are determined from equations 3a, 3b, and 3c modified by the additive constants.

As seen from Table VII and the discussion of the formula, the tristimulus values, X, Y, Z, of the sample to be predicted in any illumination must be known for that illumination and new tristimulus

Figure 5. Predicted departures from daylight chromaticness for eleven Munsell samples viewed under the 3500K fluorescent source. The circles indicate the chromaticity points in the (x,y)-diagram of the 1931 CIE system for the samples illuminated by CIE source C (representative of average daylight). The dots indicate the corresponding chromaticity points for the samples illuminated by the fluorescent source. The arrow heads indicate corresponding chromaticity coordinates (x', y') adjusted in accord with modified equation 3 to take account of the chromatic adaptive state of the observer. Double circle refers to source C; square to fluorescent source.



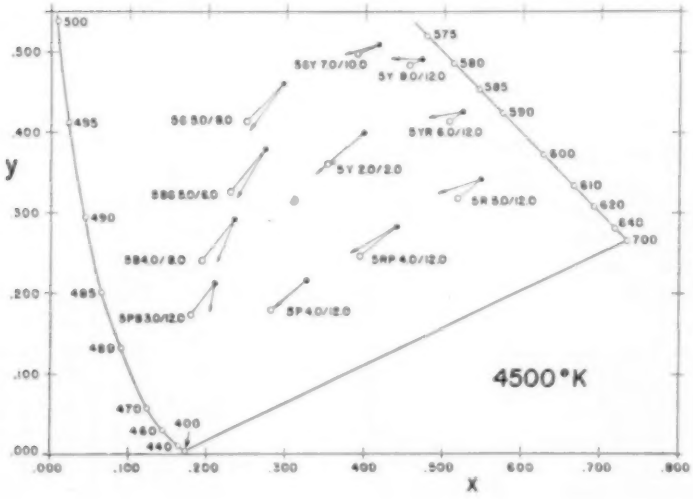
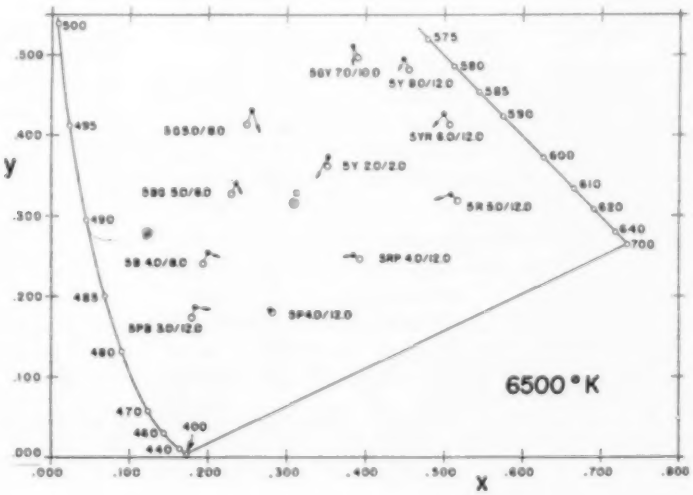


Figure 6. Predicted departures from daylight chromaticness for eleven Munsell samples viewed under the 4500K fluorescent source. Circles, dots, arrow heads, and square have same meaning as in Fig. 5

Figure 7. Predicted departures from daylight chromaticness for eleven Munsell samples viewed under the 6500K fluorescent source. Circles, dots, arrow heads, and square have same meaning as in Fig. 5



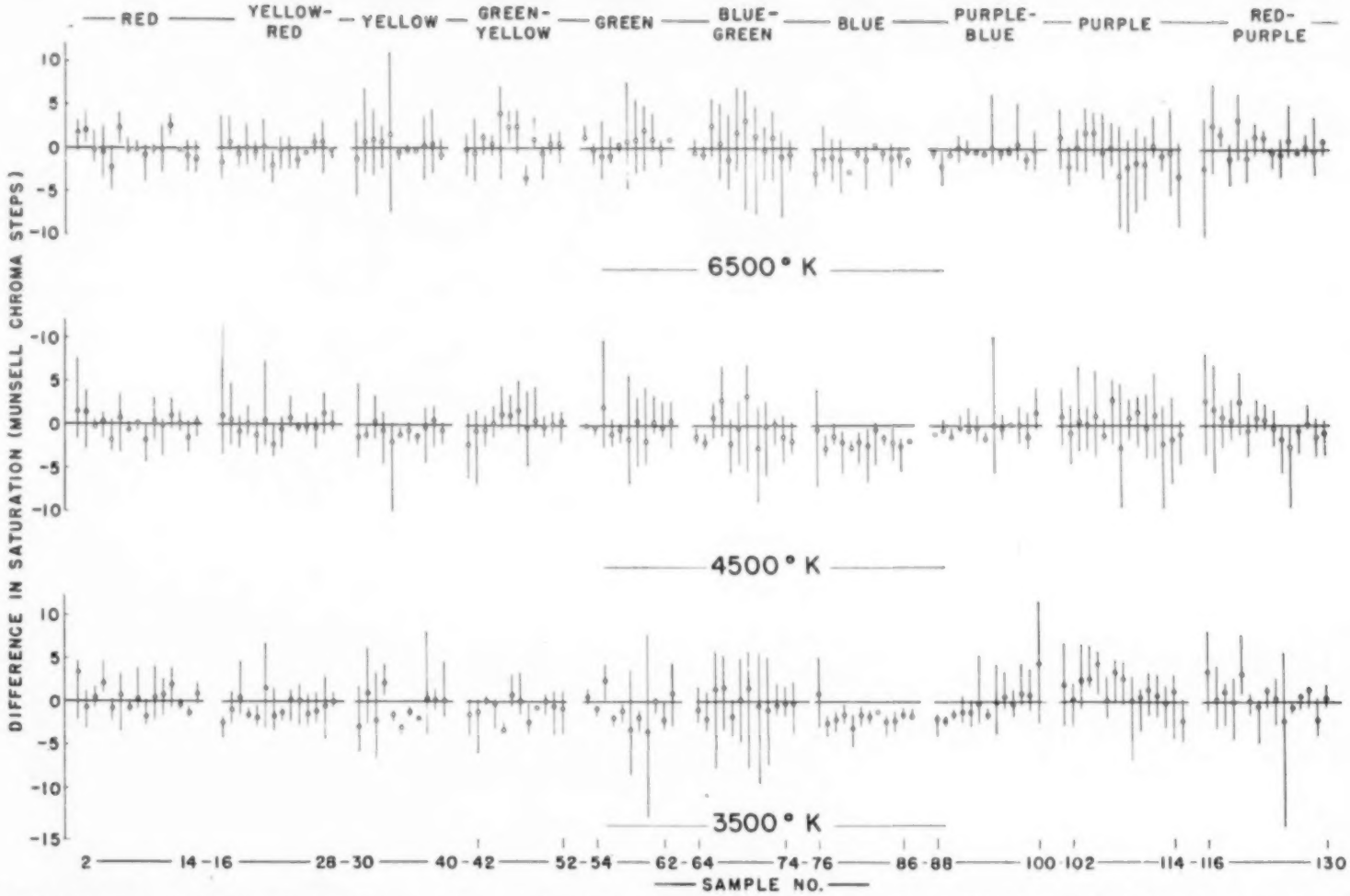


Figure 8. Departures of the experimental means from the predicted hues of the colors perceived to belong to the 130 Munsell samples illuminated by three fluorescent sources. The abscissa shows the serial numbers of the samples in the order used for Tables II, III and IV and grouped as in those tables according to Munsell hue. The circles represent the differences on the Munsell 100-hue scale between the experimentally found hues (means of 5 observers) and the hues predicted in accord with computations as in Table VII. The vertical solid lines, indicate by their length the extent of the individual-observer ranges in hue estimates, and by their positions relative to the horizontal base lines (representing predicted hues) whether the predicted hues fall within the individual-observer ranges. Note that the majority of these vertical lines intersect the base line, indicating that the predicted hues do fall within the inter-observer ranges. Note also that for the specimens in the blue hue range, there is a small, but regular and apparently significant, exception to this general rule for all three fluorescent sources.

values, X′, Y′, Z′, must be computed according to the equation indicated in Table VII to take account of the changed state of adaptation of the eye in that illumination as compared with daylight (here taken as C.I.E. source C). After X′, Y′, and Z′ have been determined, chromaticity coordinates, x′, y′, z′, are determined in the usual manner from the tristimulus values and the predicted color is found from a plot of the renotated Munsell colors in the C.I.E. color mixture diagram (Newhall, Nickerson, and Judd, 1943). Since the Munsell grid is by value level it is necessary in general to interpolate between adjacent value levels for Munsell hue and chroma. Munsell hue and chroma, so found, are the predictions for hue and saturation of the color perceived to belong to the specimen under the fluorescent source.

The method of determining the changes in hue and saturation in passing from daylight to any other type of illumination, according to the theory underlying the present study, is graphically illustrated in Figs. 5, 6, and 7 wherein are plotted 11 Munsell samples (1) according to their C.I.E. specifications in daylight, (2) in each of the three fluorescent illuminants, and (3) according to the correction factors applied to take into account the altered state of visual adaptation to the fluorescent illuminant.

The 11 samples are identified by Munsell book notation. The corresponding renotations (see Tables III, IV, and V) are as follows: 5.5R 5.0/12.8, 6.0YR 6.2/11.5, 5.5Y 7.9/12.3, 5.0Y 2.5/1.4, 4.0GY 7.0/9.5, 5.0G 4.9/8.2, 5.0BG 5.1/6.4, 6.5B 4.0/6.9, 4.0PB 3.3/9.4, 5.5P 4.1/12.6, and 5.0RP 4.3/10.7.

From the plots in Figs. 5, 6, and 7 it is seen that the corrected C.I.E. coordinates of the samples are for the most part quite different from their corresponding uncorrected coordinates, though, in general, fairly close to the daylight coordinates of the specimen. In this way, these differences are expressed wholly in terms of the C.I.E. color mixture diagram. The predicted hues and saturations can be read in Munsell terms from a plot of the renotated Munsell colors in the C.I.E. color mixture diagram (Newhall, Nickerson, and Judd, 1943).

5. Agreement Between Calculated And Observed Results

To test the adequacy of the formulas in predicting the changes in hue from daylight to the three fluorescent lights employed in this study a graph (Fig. 8) showing departures from the predictions relative to the individual-observer ranges has been prepared, and Wilcoxon's test of significance of differences between paired replicates, a non-parametric test, was used (Wilcoxon, 1949). In Fig. 8, the abscissa is the serial number of the sample in the order listed in Tables II, III, and IV. The plotted circles indicate the differences on the Munsell numerical hue scale between the estimated hues (means of five observers) and the hues computed as in Table VII. The upper ends of the vertical solid lines similarly represent the differences between the highest hue estimate among the five observers and the hues computed as in Table VII; and the lower ends refer to the lowest estimate; so the length of the line indicates the inter-observer hue range. The three horizontal base lines represent the predicted hues for the three fluorescent sources. Note the markedly greater individual-observer differences, so far unexplained, for the blue-green, purple and red-purple samples compared to most samples of other hues. Most of the occasional large ranges for these other hues are ascribable to the samples being rendered nearly gray (3.5Y 7.8/1.6 and 6.5G 7.8/2.1 for 6500K source); but other large ranges are unaccounted for (5.5P 5.0/6.7 for 4500K source, 5.0BG 5.1/6.4 for 6500K source and 6.0G 8.7/2.7 for 3500K source). Note also that the vertical lines in most cases intersect the base lines; that is, in general, the predicted hues fall within the inter-observer ranges. Furthermore the circles are scattered in more or less random fashion about the base lines; that is, there is generally no regular trend in the indicated departures of experiment from theory. An outstanding exception is formed by the blue samples. Fig. 8 shows not only that a preponderance of the hue-estimate averages in the blue region are greener than the predicted hues for all three sources, but in addition, so many of the ranges are entirely on the green side of the predicted hues that a significant difference between theory and experiment is strongly indicated.

To obtain an evaluation of the significance of such trends, the Wilcoxon non-parametric test was employed. The 130 Munsell samples were originally chosen to divide about equally among the Munsell 10 major hues given in Table V and shown separated in Tables II, III, and IV and on Fig. 8. The significance of the differences between the theoretically computed hues and the average estimates of the hues (corrected for the departure of the observers' hue estimates in Macbeth daylight from the Munsell renotations) was determined for each of the ten major Munsell hues, making 30 distinct statistical tests (Table V). As might have been expected from Fig. 8, the agreement between formula and observation is, on the whole, shown

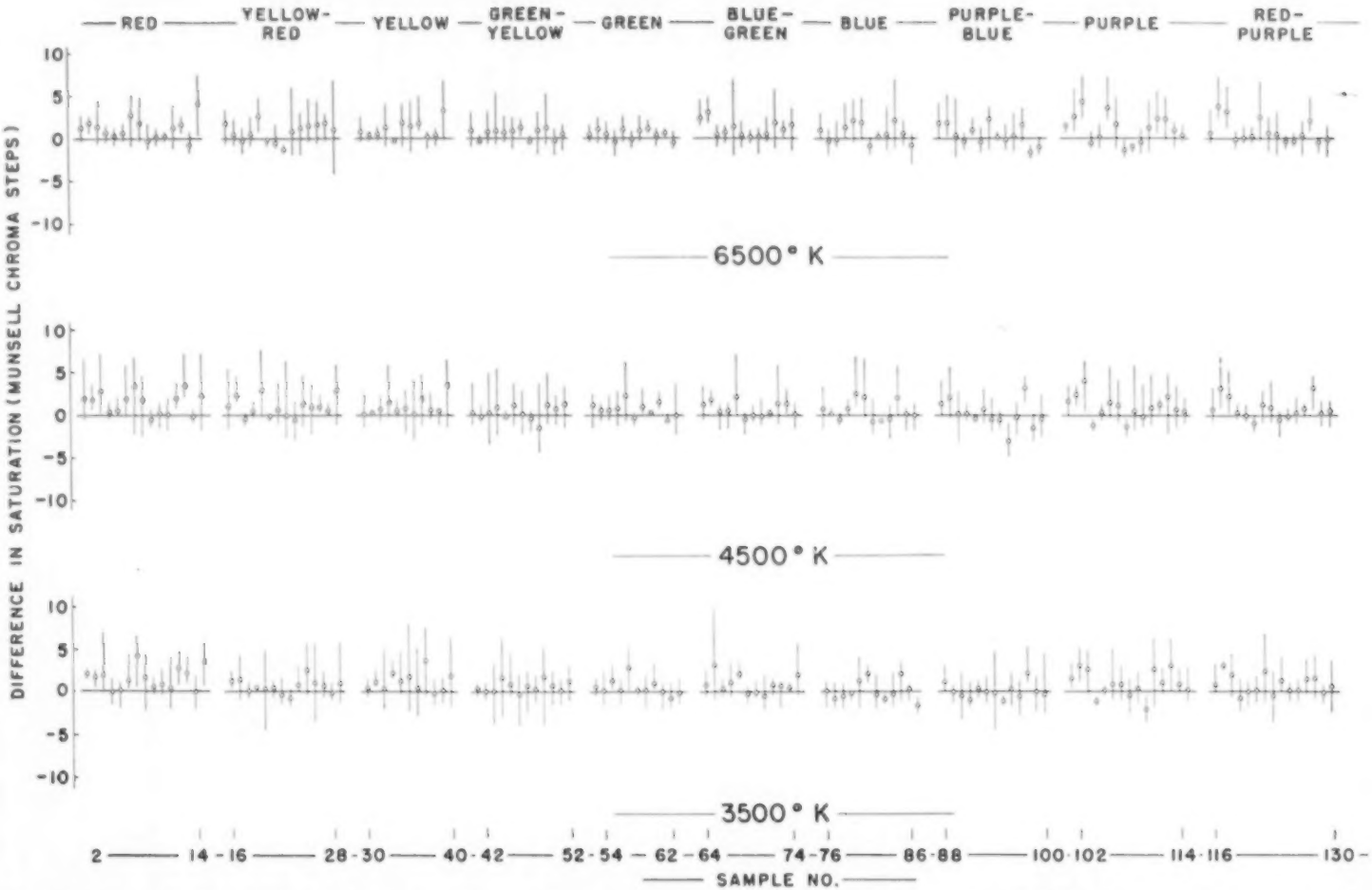


Figure 9. Departures of the experimental means from the predicted saturations of the color perceived to belong to the 130 Munsell samples illuminated by three fluorescent sources. The abscissa shows the serial numbers of the samples in the order used for Tables II, III and IV and grouped as in those tables according to Munsell hue. The circles represent the differences on the Munsell chroma scales between the experimentally found saturations (means of five observers) and the saturations predicted in accord with computations as in Table VII. The vertical solid lines indicate by their length the extent of the individual-observer ranges in saturation estimates, and by their positions relative to the horizontal base lines (representing predicted saturations) whether the predicted saturations fall within the individual-observer ranges. Note that the majority of these vertical lines intersect the base line, indicating that the predicted saturations do fall within the individual-observer ranges. Note also that the five-observer averages of estimated saturation tend to be higher than the predicted saturations by about one Munsell step for each of the three types (6500, 4500, 3500) of fluorescent lamp studied.

by the Wilcoxon test to be excellent, the *direction* of hue shift being correctly predicted in 20 out of the 30 comparisons. Only two of the ten discrepancies between observed and predicted directions of hue shift are statistically significant (blue in 6500K and 4500K). The Wilcoxon test corroborates quantitatively the qualitative indication of Fig. 8 that there is a significant discrepancy between observation and theory for the blue samples viewed under all three sources studied, but since this discrepancy is substantially the same for the 6500K fluorescent lamp causing slight chromatic-adaptation change from daylight as for the 3500K fluorescent lamp involving considerable chromatic-adaptation change, the explanation of the discrepancy should probably be looked for elsewhere than in our formulation for the effect of chromatic-adaptation change, perhaps in failure of the C.I.E. standard observer to represent the five observers actually used. Of the seven statistically significant discrepancies in Table V between formula and observation, five concern differences in the *amount* of hue shift only, the calculated shift in four cases being greater than that observed. We can therefore regard the present formulation as adequate to predict the changes in hue with change in illumination found in this study in the sense that the significant discrepancies are of the order of magnitude of the individual-observer differences.

Fig. 9 is a plot of observed saturations minus the predicted saturations against the serial number of the Munsell sample. It shows for saturation the average and the range compared to the prediction just as Fig. 8 shows these for hue. Table VI shows for samples of each of the 10 Munsell hues the average observed saturation change from daylight to fluorescent illumination, and the average predicted saturation change. We find from Table VI that the formulas predict loss of saturation for almost all of the hues, but in most cases an actual, though slight, gain in saturation was observed for the three sources as compared with daylight. Since the observed gain in saturation is on the average less than one-quarter of a Munsell step it must be concluded that saturation remains practically constant with change in quality of illumination of the order investigated here. This result agrees well with that found in the previous study comparing the color rendition of incandescent-lamp light (C.I.E. source A) with daylight (C.I.E. source C) and indicating an average rise in saturation of one-tenth of a Munsell step. The predicted changes in saturation are less than a Munsell step on the average and since the observers were trained to respond to saturation differences corresponding to only one step of Munsell chroma, most of the discrepancies between formula and observation can be regarded as well within the discrimination tolerance of the observers. On the other hand, in view of the predominant number of predicted losses in saturation as compared with the observed gains, suspicion may well be directed to the empirical modifications, $0.020X_c$, $0.020Y_c$, $0.020Z_c$, introduced on the basis of the previous study of incandescent-lamp light (Helson, Judd, Warren, 1952). These modifications reduce the predicted saturations in every case, and computation for a representative group of samples indicates that on average they reduce the predicted saturations by a little less than one Munsell step. In other words, if the modifications had not been introduced the predicted saturation changes would have averaged slightly plus in agreement with the observations. It may be concluded that the present observations support the simple theory (equation 3) better than the empirically modified theory actually used in the computations (Table VII).

In view of the well-established correlation (Judd, 1940) between lightness of the perceived color and luminous directional reflectance (Y in the C.I.E. system) of the object for the source used, which forms the basis of the theoretical estimates here, it is not necessary to test the agreement of theory and observation statistically to determine goodness of fit for lightnes. The theoretical values for lightness can be seen by inspection to be in excellent agreement with the observed, the average difference (Tables II, III, and IV) being less than 40 per cent of the uncertainty (one Munsell value step) of each observation.

6. Conclusion

The rendition of object colors by a light source depends upon the spectral reflectances of the objects, the spectral distribution of the radiant energy emitted by the source, and the adaptive state of the eye. Previous studies have shown that a simple three-components theory of vision provides formulas by means of which predictions of object-color perceptions under incandescent-lamp light may be made from these determining factors. The present study employed three fluorescent sources of chromaticity intermediate to incandescent-lamp light and daylight, and included many more specimen objects (130) than the previous studies. It is shown that the average judgments of color perception by five observers are satisfactorily accounted for by the same formula approximately validated in the previous study (equation 3). This formula differs from that actually used in the pres-

ent computations by omission of the empirical modification based on the previous study and inserted as a refinement of the simple theory. The present observations support the simple theory better than the supposed refinement. To obtain the predictions of hue, lightness, and saturation from equation 3 in terms of the Munsell renotation system it is necessary to find the Munsell renotation corresponding to X′, Y′, Z′ by tri-dimensional interpolation in the charts defining the ideal Munsell system (Newhall, Nickerson, Judd, 1943).

An outstanding result of this study is that, while the averages of five individual judgments on each of the colors are satisfactorily accounted for by this formula, the individual judgments themselves show wide variation. This result was also found in the study of incandescent-lamp light. We do not know whether the disparities are ascribable chiefly to the uncertainty, admittedly rather large, inherent in the difficulty of the absolute judgments of hue, lightness, and saturation required of the observers, or whether the sources used actually produced rather widely varying adaptive effects on the different observers. We incline to the view that the individual variations arise from a combination of these, and perhaps other factors.

An important consequence of the imprecise nature of the method and of the large individual differences is that the formulas shown not to be significantly in error by the observations have still not been given the strictest tests possible. This may be seen from the many disparities between the computed and observed results in Figs. 3, 8 and 9 and in Tables II, III, and IV. We do not know whether these disparities are due to a wrong form of theory, such as failure to take account of the reflectance ratio of specimen to background which is known to influence color perception (Helson, 1938; Judd, 1940), or to other error sources, such as failure of the light sources to emit radiant flux of the spectral energy distributions used in the calculations, or the failure of the color specimens to have the spectral reflectances used in the calculations, or failure of the C.I.E. standard observer to represent the actual observers.

To settle these questions would seem to require a procedure involving a higher order of precision than our method of absolute judgment of hue, lightness, and saturation; for example, a procedure such as the binocular matching technic (Wright, 1934; Schouten and Ornstein, 1939; Walters, 1942; Hunt, 1950; Winch and Young, 1951; Burnham, Evans and Newhall, 1952; Brewer, 1954). This technic is also better adapted than ours to determine precisely the primaries of the three-components system giving optimum predictions, and to discover formulas, perhaps not based on the three-components theory, that will yield precise predictions for each observer rather than approximate predictions for an average group of observers.

The present study, in spite of its imperfections, has shown that a quantitative formulation designed to take account of the effects of adaptation applies not only to fairly smooth spectral energy distributions but also to such irregular energy distributions as are yielded by fluorescent lamps. This finding supports the belief that the effects of adaptation of moderate degree can be accounted for by the proper set of primaries and a quantitative theory which is applicable to all types of spectral energy distribution.

Acknowledgments

The present investigation was made possible by a grant from the I.E.S. Research Fund. We are also indebted to Miss Dorothy Nickerson of the Production and Marketing Administration of the U. S. Department of Agriculture for providing the measured fluorescent sources and the Munsell samples used in this study and for her active cooperation in all phases of the problem.

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INSTALLATION AT CALIFORNIA FEDERAL SAVINGS & LOAN ASSOCIATION
10682 WEST PICO BOULEVARD, LOS ANGELES, CALIFORNIA.

Lighting a Savings and Loan Bank

LIGHTING OBJECTIVE: To provide attractive general lighting for negotiation and banking operations and accent lighting for the decorative plants and architectural features.

GENERAL INFORMATION: The main area for consultations shown above measures approximately 40 feet by 90 feet with a 14-foot ceiling. Color, reflectances and brightness of room surfaces are as follows:

ceiling, acoustical tile	white	75% RF	5.5 ft-L
walls			
wood	medium brown	18% RF	7 ft-L
plaster	light brown	30% RF	12 ft-L
brick	light brown	30% RF	12 ft-L
floor, terrazzo	light brown	38% RF	15 ft-L
main counters			
top	light brown	31% RF	12 ft-L
sides	light tan	48% RF	3.1 ft-L
executive desks	medium brown	17% RF	4.2 ft-L
customer writing desks	light brown	31% RF	11 ft-L
chairs	medium blue	40% RF	6.5 ft-L
couches	brown (rough texture)	19% RF	2.5 ft-L
planter boxes	light brown	30% RF	2.2 ft-L
vault door	steel	30% RF	4.0 ft-L
decorative stone (around vault door)	light green	54% RF	9.1 ft-L

At the south end of the building there is a drive-in banking window, as shown in Fig. 2.

(over)

A.I.A. File No. 31

Figure 2. Daytime view showing drive-in banking window.

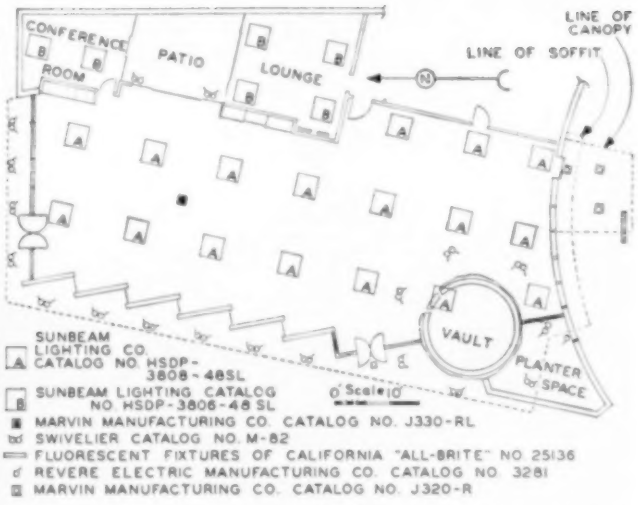

Figure 3. Plan view showing location of all lighting equipment.

INSTALLATION: Fig. 3 shows the location of all lighting equipment. General illumination is provided by seventeen Sunbeam Lighting Co. catalog no. HSDP-3808-48SL luminaires each using eight 48-inch T-12 standard cool white slimline fluorescent lamps. One accent light (Marvin Manufacturing Co. "Marco" no. J330-RL), equipped with a 150-watt R-40 flood lamp and a concentric ring louver, is recessed in the ceiling over the executive desk area. Accent lighting around the vault, two exterior sides of the building, and in the patio is provided by nineteen Swivelier catalog no. M-82 double canopy shade units. Each unit is equipped with two 75-watt R-30 flood lamps.

General lighting in the lounge and conference room is provided by six Sunbeam Lighting Co. catalog no. HSDP-3806-48SL luminaires each using six 48-inch T-12 standard cool white slimline fluorescent lamps. Two "All-Brite" units (Fluorescent Fixtures of California catalog no. 25136), each equipped with a 30-watt T-8 standard cool white fluorescent lamp, are used as cove lighting in the lounge. Accent lighting in the planter space is provided by one Revere Electric Manufacturing Co. catalog no. 3281 accent light equipped with a 150-watt PAR-38 spot lamp. Three "Marco" downlights (Marvin Manufacturing Co. catalog no. J320-R), each equipped with one 150-watt R-40 flood lamp, are recessed in the canopy over the drive-in banking window as shown in Fig. 2.

The average general illumination over the negotiation area is 35 footcandles, with 50 footcandles on the banking counter. Room surface brightnesses are listed above under General Information; square luminaire brightness at 30 degrees is 630 footlamberts.

Lighting Designer and Electrical Engineer: Henry Simmons, 5709 California St., Long Beach, Calif.; Architect: Francis J. Heusel, A.I.A., 730 East Third St., Long Beach, Calif.; General Contractor: Pozzo Construction Co., 2403 Riverside Drive, Los Angeles, Calif.; Electric Contractor: Pacific Western Co., 1836 Fourth St., Santa Monica, Calif.

Lighting data submitted by Don Romanoff, Ruby Lighting Corp., 1212 South Olive St., Los Angeles, Calif., as an illustration of good lighting practice and to aid in the design of similar installations.

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Series XXI 4-56

TELECAST

LIGHTING NEWS OF CURRENT INTEREST

I.E.S. Celebrates Its Fiftieth Anniversary

More Sections and Chapters of the Society have held their special birthday party meetings, celebrating the Fiftieth Anniversary of I.E.S. (see March IE, page 7A, for first reports).

Birthday cakes and the gold Anniversary pin, designating its winner as the representative to the Boston Conference next September, have proved most popular features of these meetings. These star attractions are supplemented by local ideas to make each celebration unique.

TWIN PORTS CHAPTER

January 10, Duluth Athletic Club, Duluth, Minn.

Members of the local chapter of AIEE were especially invited to join the Twin Ports Chapter members in their celebration of the IES Fiftieth Anniversary. Added attraction at the meeting was the speech on the anniversary by Larry Nichols, Vice-President and General Sales Manager with Superior Water, Light & Power Co.

Russell D. Churchill, General Electric Co., was the main speaker with the subject, "Varieties of Fluorescent Lamp Operation."

WINNIPEG CHAPTER

January 10, Westinghouse Auditorium, Winnipeg, Man.

The Golden Anniversary meeting of the Winnipeg Chapter, IES, featured Charlie Midwinter, authority on street lighting, who gave highlights of his tour around the world.

The Anniversary cake was shared by all those attending.

ROCKY MOUNTAIN SECTION

January 25, American Legion, Denver, Colo.

The official Anniversary pin was won by Past-Chairman of the Rocky Mountain Section and Past-Regional V-P of the Inter-Mountain Region, Jim Buck, at the Rocky Mountain Section's I.E.S. birthday party.

Speaker at the meeting was Brooks Chassaing, Director of the Society.

ROCKY MOUNTAIN SECTION. Fiftieth Anniversary party was held January 25, at the American Legion, in Denver.

EASTERN PENNSYLVANIA SECTION

January 17, Berkshire Hotel, Reading, Pa.

Over 100 members attended the Eastern Pennsylvania Section's Anniversary meeting, when Paul Hildebrand, Past Regional Vice-President of the East Central Region spoke on the early history of I.E.S., and on the formation and development of the Section.

Another speaker was Donald R. Brown, of Crouse-Hinds. Fred M. Gochenaur, Section Chairman, presided.

NEW ORLEANS SECTION

January 18, Lenfant's Restaurant, New Orleans, La.

A birthday cake, crowned with fifty golden candles, highlighted the Fiftieth Anniversary celebration of I.E.S. by the New Orleans Section. Baked in the cake was the Golden Anniversary pin, which was found in his slice by George J. Segel, New Orleans Public Service Co. Mr. Segel thus becomes his Society's official representative to the Boston Conference.

NEW ORLEANS SECTION. George M. Morris, Assistant Vice-President of the Southern Region, I.E.S., cuts the birthday cake, which was crowned with 50 golden candles.

The cake was cut by George M. Morris,

Assistant Vice-President of the Southern Region, who was also Keynote speaker. Mr. Morris reviewed the past fifty years of the Society, pointing up its growth, its research and study, and its contributions in the development of lighting.

R. Cecil Paslay, past Regional V-P, also spoke, tracing the history of the New Orleans Section since its organization in 1939. Mr. Paslay introduced several charter members of the Section who were present.

J. M. Gensburger, Section Chairman, presided at the meeting; C. S. Berdon introduced the speakers.

ISCC Holds 25th Annual Meeting

Color Problems in the Graphic Arts was the overall theme of the two-day meeting, comprising the 25th Annual Meeting of the Inter-Society Color Council, held in New York City April 5 and 6 at the Statler Hotel. Norman Macbeth, ISCC Treasurer and Chairman of the delegation from IES, was Program Chairman. O. C. Holland, delegate from the National Association of Printing Ink Makers, Inc., was Chairman of the Local Arrangements Committee.

Reports of the chairmen of the delegations from the 23 Member-Bodies and of the various committees, as well as the business session, were held Thursday morning, April 5.

On Thursday afternoon and all day Friday, April 6, the following papers were presented:

Color Printing Methods in the Graphic Arts — Dr. Marvin Rogers, R. R. Donnelley and Sons Co.

Tone Reproduction in Graphic Arts' Processes — Warren L. Rhodes, Rochester Institute of Technology.

Color Correction by Photographic Masking — Dr. Walter Clark, Eastman Kodak Co.

Applications of Scanning Methods to the Graphic Arts — Vincent C. Hall and Joseph G. Jordan, Time, Inc.

Outline of Color Problems in the Press Room — Gordon Dalsemer, Lord Baltimore Press.

Paper Controls in Graphic Arts — John L. Kronenberg, S. D. Warren Co.

Color Matching and Control of Printing Inks — C. R. Conquergood, Canada Printing Ink Co.

Printing Controls at the Press — Daniel Smith, Interchemical Corp.

Use of Color Systems in the Graphic Arts — Carl E. Foss, Roslyn, N. Y.

Lighting for Color Control and Visual Color Appraisals in the Graphic Arts — Warren B. Reese, Macbeth Corp.

The Role of the Publisher in the Color Problem — F. E. Church, Time, Inc.

The Role of the Art Director — Albert Kner, Container Corp. of America.

In connection with the meeting an exhibit showed equipment and demonstrations consisting of colorimeters, densitometers, lighting equipment, package design, viewers, spectrophotometers, and samples of process printing, including samples of process printing where a scanner was employed.

The banquet was held on Friday evening in the Georgian Room of the Statler, followed by a paper by Ralph M. Evans on problems in the graphic arts, entitled, "Reproduction of Color Photographs."

CONFERENCE PLANNERS — Looking ahead to the 50th National Technical Conference of IES, to be held in Boston next September, the Conference Executive Committee held a meeting January 10. Left to right are, seated: C. W. McCormick, Northeastern Regional V-P; R. B. Brown, Jr., Chairman, 1956 Conference Executive Committee; W. B. Elmer, Chairman, New England Section. Standing: Fred Vorlander, R. F. Townsend, R. W. Wilson and N. E. Ticehurst, Coordinators of the Conference Executive Committee.

Two I.E.S. Study Clubs Approaching Chapter Status

Chapters Numbers 73 and 74 of I.E.S. may be coming along in the near future, with interest and activity in Calgary, Alta. and in Western Massachusets. Both these Study Clubs are holding regular meetings.

An attendance of 38 at the January 23 meeting of the Berkshire (Western Massachusetts) group represented a cross section of the electrical industry and allied fields. Included in the group were architects, electrical contractors, distributors, and their salesmen, representatives of lamp and fixture manufacturers, optometrists and utility personnel. The next meeting, with dinner, in Springfield, Mass., featured Larry Cooke, District Engineer for the General Electric Co., who spoke on "The Science of Seeing."

The Calgary Study Club held a regular monthly meeting on March 14, when J. H. Gilbreath, Western District Engineer, Holophane Co., Ltd., Vancouver, presented a speech on "Let's Keep Control."

Partial Roster Compiled of I.E.S. Section/Chapter Membership

Forty-four of the Society's 72 Sections and Chapters have compiled directories of their membership, which have been assembled at Headquarters to form a partial membership roster. A limited number of these sets are available upon request for national officers, national committees and others, while the supply lasts.

Safety Engineers Launch New Technical Journal

February 1956 issue was Volume 1, No. 1 of *The Journal of the American Society of Safety Engineers*, a quarterly technical publication, intended to give safety engineers and others new knowledge in safety which is being developed through experience and on-the-job experience. The pages of the magazine will carry discussions of safety philosophy and present opposing opinions on controversial issues in an effort to stimulate discussion of these issues and encourage

the investigation and research through which they may be resolved.

The magazine, which is edited at ASSE's headquarters at 425 North Michigan Ave., Chicago 11, Ill. is under the direction of J. B. Johnson, Managing Director; Robert E. Beighley, Editor; Charles S. Wolff, Associate Editor.

Progress in Engineering Shown At University Expositions

The University of Miami, Coral Gables, Fla., sponsored an "Engineers' Exposition" on February 24, in recognition of National Engineers Week. The exposition demonstrated the laboratory facilities of the school, and also featured a continuous series of non-technical 16mm sound movies, dealing with engineering and science phenomena. Among the exhibits were demonstrations of the following nature: a pre-stressed diving board; aircraft communication system; closed television circuit; automobile television; household wiring methods; solar batteries, electronic computers and turbojet engines.

Another exhibition of progress in engineering research and education will be the "Engineering Showcase," being sponsored by the students and faculty of Wayne University, Detroit, Mich. on April 27 and 28. Here also, the University's engineering facilities will be shown as well as displays of the work of students during their four years in the college. Guided tours will include student explanations of the relation of their projects and laboratory work to the problems of industry. The "Showcase" will include models and displays from all major fields of engineering, ranging from a model nuclear reactor, a wind tunnel for testing supersonic aircraft, the Mackinaw Bridge, to the manufacture of table salt.

Engineers and Scientists Wanted by Patent Office

American industry is facing long delays in obtaining patent coverage for products and processes otherwise ready for the market, according to reports made at a recent meeting of the New York Patent Law Association, which was addressed by the Commissioner of Patents.

These delays stem from the great increase in the number of patent applications filed during the past few years. This flood of inventions has stretched the average prosecution time per patent to three and a half years.

The Association points out that the Patent Examiner thus holds a key position in the advancement of American technology and that the only way to reduce these delays and clear the way for marketing the new products and processes is to employ new Patent Examiners to pass upon the backlog of applications which is piling up in almost every technical field.

Steps have already been taken in this direction and approximately 100 new Patent Examiners have been added to the examining staff since last June. It is understood that the Patent Office wants 300 new Patent Examiners in 1956 — 125 in the first quarter, 25 in the second, and 75 in each of the last two quarters. There are immediate openings for engineers and scientists who can accept appointments in Washington now.

Patent Examiners pass upon applica-

LIGHTING CALENDAR

Society Events

April 19-21, 1956 — Pacific Northwest Regional Conference, Davenport Hotel, Spokane, Wash.

April 26-28, 1956—Inter Mountain Regional Conference, Utah Hotel, Salt Lake City, Utah.

May 7-8, 1956—Great Lakes Regional Conference, Commodore Perry Hotel, Toledo, Ohio.

May 10-11, 1956—Midwestern Regional Conference, Severin Hotel, Indianapolis, Indiana.

May 17-18, 1956 — Canadian Regional Conference, Chateau Frontenac, Quebec, Canada.

May 24-25, 1956 — East Central Regional Conference, Shoreham Hotel, Washington, D. C.

September 17-21, 1956 — Illuminating Engineering Society, National Technical Conference, Hotel Statler, Boston, Mass.

September 9-13, 1957 — Illuminating Engineering Society, National Technical Conference, Biltmore Hotel, Atlanta, Ga.

Industry Events

April 29 - May 4, 1956 — Society of Motion Picture and Television Engineers, Hotel Statler, New York, N. Y.

May 3-4, 1956 — National Farm Wiring Conference, LaSalle Hotel, Chicago, Ill.

May 19-20, 1956—International Home Building Exposition, New York Coliseum, New York, N. Y.

May 21-22, 1956 — Building Research Institute, Fifth Annual Meeting, Sheraton-Brock Hotel, Niagara Falls, Ont.

June 4-7, 1956 — Edison Electric Institute, 24th Annual Convention, Atlantic City, N. J.

Week of June 10, 1956—National Association of Electrical Distributors (48th Annual Convention), Ambassador-Chelsea Hotels, Atlantic City, N. J.

June 11-15, 1956 — Technical Conference on Plastics, New York Coliseum, New York, N. Y.

June 25-29, 1956—American Institute of Electrical Engineers, (Summer & Pacific General Meeting), San Francisco, Calif.

June 27-July 5, 1956—International Electro-Technical Committee, Munich area of Southern Germany.

October 1-5, 1956—American Institute of Electrical Engineers (Fall General Meeting), Morrison Hotel, Chicago, Ill.

October 2-4, 1956—Canadian Electrical Manufactureres Association (12th Annual Meeting), Sheraton Brock Hotel, Niagara Falls, Ontario, Canada.

October 7-12, 1956 — Society of Motion Picture and Television Engineers, Ambassador Hotel, Los Angeles, Calif.

October 22-24, 1956 — American Standards Association, 38th Annual Meeting (In conjunction with Seventh National Conference on Standards), Hotel Roosevelt, New York, N. Y.

October 22-26, 1956—National Safety Council, 44th National Safety Congress & Exposition, Chicago, Ill.

November 12-16, 1956—National Electrical Manufacturers Association (Annual Meeting), Traymore Hotel, Atlantic City, N. J.

January 21-25, 1957 — American Institute of Electrical Engineers, Winter General Meeting, Hotel Statler, New York, N. Y.

February 17-20, 1957 — National Electric Sign Association, Annual Convention and Exhibit, Sheraton Park Hotel, Washington, D. C.

March 11-14, 1957 — National Electrical Manufacturers Association, Edgewater Beach Hotel, Chicago, Ill.

May 6-8, 1957 — Air Conditioning and Refrigeration Institute, Annual Meeting, The Homestead, Hot Springs, Va.

May 7-9, 1957 — Chicago Electrical Industry Show, Chicago, Ill.

June 24-28, 1957 — American Institute of Electrical Engineers, Summer General Meeting, Montreal, Que.

August 28-30, 1957 — American Institute of Electrical Engineers, Pacific General Meeting, Yakima, Wash.

October 7-11, 1957 — American Institute of Electrical Engineers, Fall General Meeting, Chicago, Ill.

October 21-25, 1957 — National Safety Council, 45th National Safety Congress & Exposition, Chicago, Ill.

November 11-15, 1957 — National Electrical Manufacturers Association, Traymore Hotel, Atlantic City, N. J.

DISPLAY of fixtures presented by manufacturers' agents preceded and followed the February 14 meeting of the I.E.S. Michigan Section, which featured the annual Progress Report presented by Ted Brown, Lamp Division, General Electric Co. In photo at left, Professor E. L. Fairchild, Section Chairman joins Mr. Brown in inspection of display. At right, a group of members also examine the fixtures. Fred Ready, of Detroit Edison, was program chairman. The meeting was held in the Detroit Edison Auditorium.

tions for patents in a wide range of technical fields to determine whether they are novel and whether invention is involved. This calls for a study of the issued patents and the related scientific literature. The Association points out that technical graduates who apply will find the job both interesting and stimulating and one which will keep them in close touch with the latest developments.

Salaries for Examiners start at $4,345 a year and it is possible to reach a salary of $7,570 within five and a half years. Engineers and scientists holding a college degree in engineering or applied science, or a degree with a major in chemistry or physics, or with certain combined credits in these fields, are eligible for appointment as Patent Examiners, without examination, upon application to the Commissioner of Patents, Washington, D. C.

"School Planning" To Coordinate Child Research by Many Sciences

A new magazine, *School Planning*, editorially devoted to building better schools, was announced in February. The new publication is described as an inter-professional magazine dedicated to scientific school design. *School Planning* will be issued bi-monthly beginning June 1, according to the announcement.

Formation is underway of an inter-professional editorial board, headed by Dr. Darell Boyd Harmon, consulting educationist, in Austin, Texas. Kenneth Wilson Hayden, Wilmette, Ill., journalist, has been appointed publishing director.

Founder of the new publication is John Marshall Ziv, consultant to school equipment manufacturers and the National Chemical & Manufacturing Co.

Self-Employed Engineers, Architects Now Under Social Security

Electrical Engineers and architects, including consultants specializing in the field of illumination, are among the self-employed groups brought under the old-age and survivors insurance program as of January 1, 1955. Such coverage is compulsory, according to Edward J. Sinder, district manager of the Midtown New York social security office.

For many such professionals this will be their first step toward getting monthly old-age insurance payments for themselves and dependents when they retire, and survivors insurance payments for their families in case of death. Engineers and architects are a substantial part of the 100,000 self-employed professionals newly covered by the law.

An engineer or architect thus covered, whether sole owner of his business, or a parner, is required to make a report of net earnings and pay the social security tax on earnings for the first taxable year after 1954, Mr. Sinder said. The report and tax for social security purposes thus becomes due on earnings for 1955, and must be filed along with the Federal income tax return, which is due April 15, 1956.

The social security tax for any self-employed person in work now under the law is three per cent of net earnings. If net earnings were $400 or more in 1955, a report must be made and the tax paid.

(Continued on page 13A)

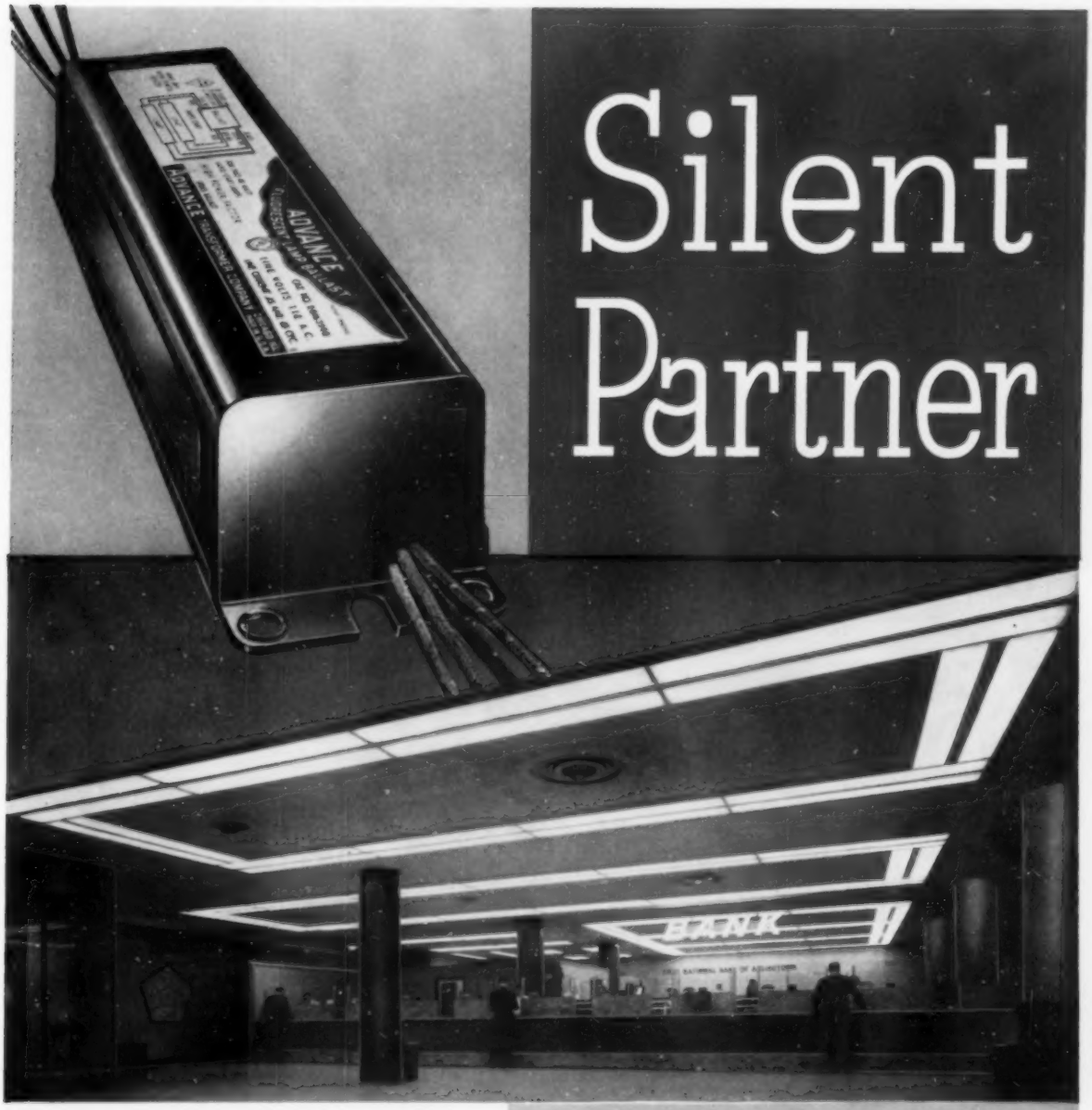
I.E.S. National Technical Conferences

1956 — September 17-21 — Hotel Statler, Boston, Massachusetts

1957 — September 9-13 — Biltmore Hotel, Atlanta, Georgia

1958 — August 17-22 — Royal York Hotel, Toronto, Ontario

1959 — September 7-11 — Hotels Fairmount and Mark Hopkins, San Francisco, California



Silent Partner

Fluorescent lighting equipment manufacturers know the performance of their product is judged by the dependability of its silent partner . . . the fluorescent lamp ballast. That's why ADVANCE is preferred by leading manufacturers like Lighting Products, Inc. of Highland Park, Illinois, who chose ADVANCE ballasts for their new "Thin-Lite" luminaire, shown in the above installation. The performance and dependability which ADVANCE fluorescent lamp ballasts provide have made ADVANCE the world's largest exclusive ballast manufacturer.

Whether you manufacture, specify, install, use or maintain fluorescent lighting, your job will be easier if you make ADVANCE fluorescent lamp ballasts your silent partner.

The Heart of the Lighting Industry

First National Bank of Arlington, Virginia (Branch). Lighting installation supervised by Earl C. Douglass, Chief Electrician, Pentagon Bldg., Washington, D. C.

ADVANCE

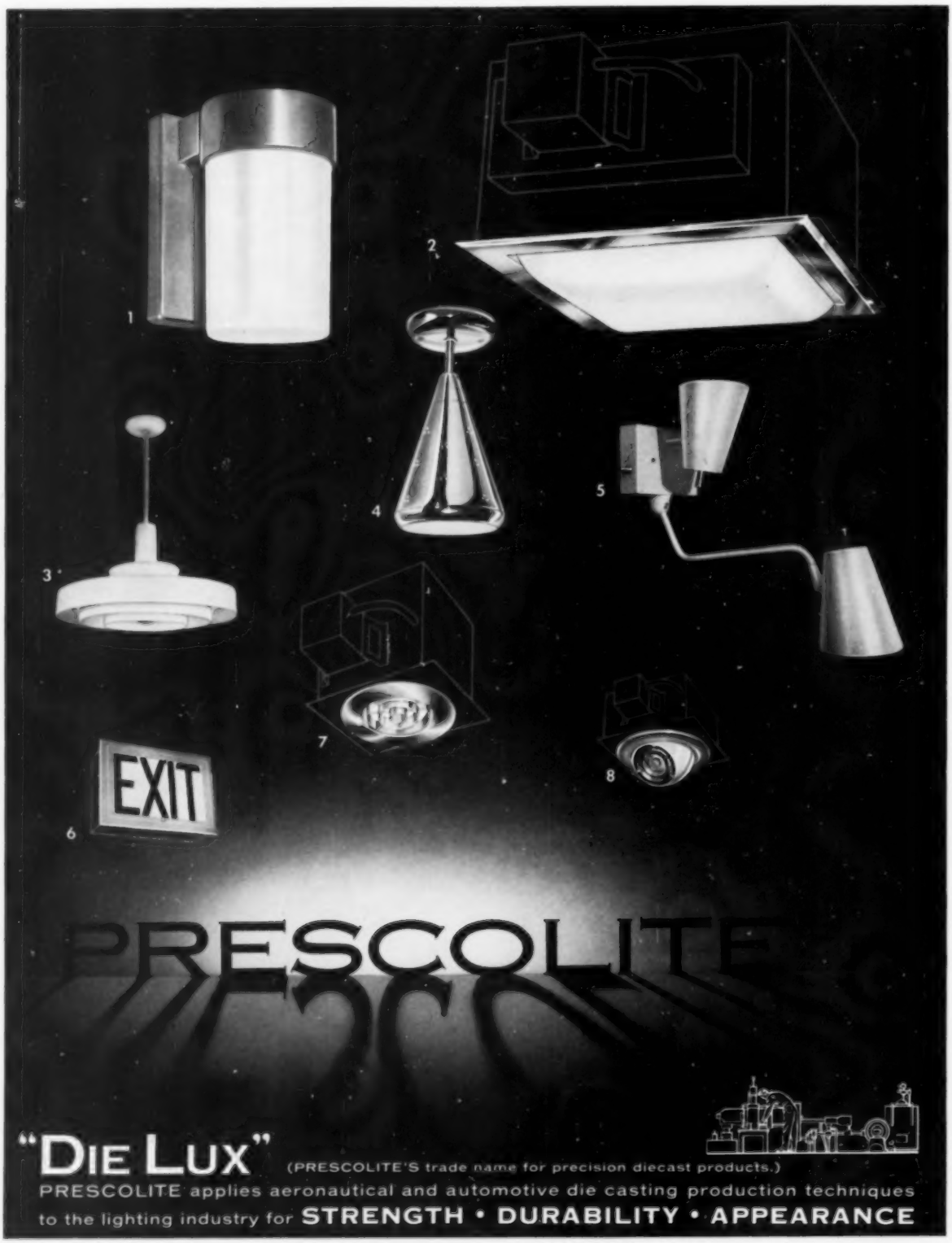
CBM CERTIFIED

World's Largest Exclusive Manufacturer of Fluorescent Lamp Ballasts

TRANSFORMER CO.

2950 No. Western Ave. Chicago 18, Illinois

Let the ADVANCE nationwide network of service-stocking distributors be your partner too, in your ballast service needs. Write for complete details and name of distributor nearest you.



"DIE LUX"

(PRESCOLITE'S trade name for precision diecast products.)

PRESCOLITE applies aeronautical and automotive die casting production techniques to the lighting industry for **STRENGTH • DURABILITY • APPEARANCE**

The fixtures illustrated above, and many more too, employ "DieLux" die castings as an integral part of the unit. 1. No. WB-24 Wall Unit. 2. No. 1313-6630 Recessed. 3. No. 300 Ring Fixture. 4. A-14 Swivel Unit. 5. No. 8585 Hospital Light. 6. No. R-54 Exit Light. 7. No. 750 Recessed. 8. No. 99 Eyeball Unit.

Write for your copies of the following PRESCOLITE literature: No. 9 (Recessed and Surface Fixtures), No. EX-1 (Exit Lights), No. LL-1 (Louver Lights), No. HD-1 (Swivel Lights), No. AE-3 (Drawings and Specs.)

PRESCOLITE Mfg. Corp., Main Office, 2229-4th St. Berkeley 10, California • Factories: Berkeley, California • Neshaminy (Bucks County), Pennsylvania

ORGANIZATIONAL meeting of the Twin City Section's Residence Lighting Forum, February 21. Above, at the head table: left to right, Mary Limberis, Home Lighting Advisor, Northern States Power Co.; L. E. "Duke" Johnson, past Section Chairman; Richard White, acting Chairman of the Forum; Cecil Branham, Section Chairman, and Mrs. Marianne Battig, acting Secretary-Treasurer of the Forum. Photo below shows general view of the 56 who attended.

(Continued from page 10A)

For each minimum taxable amount reported, a full year's social security credit is obtained; where net earnings from self-employment are under $400, no social security credit can be granted. Credit for any calendar quarter in which $50 or more in wages subject to social security taxes is paid to an employee may be had, even in a year in which a person is self-employed whether or not he realizes a net of $400.

Net earnings up to $4200 in a year are credited to a social security account and the social security tax on earnings up to that amount must be paid.

After a certain number of social security credits have been earned, one becomes insured. How long this will take depends on date of birth (and if death occurs before age 65, on date of death).

For further information as to these benefits, write, phone or visit the nearest social security district office. The address is listed at local post offices or in the telephone book under "United States Government, Department of Health, Education, and Welfare, Social Security Administration."

IES General Secretary Attends Engineers Joint Council Meeting

The IES was represented at the two-day meeting of the Engineers Joint Council, January 26-27 in New York City, by General Secretary George J. Taylor. EJC is an association of eleven engineering societies or federations with a membership of over 200,000. Objectives of the Council are (a) To advance the general welfare of mankind through the available resources and creative ability of the engineering professions; (b) To promote cooperation among the various branches of the engineering profession; (c) To advance the science and profession of engineering; (d) To develop sound public policies respecting national and international affairs wherein the enginering profession can be helpful through the services of the members of the engineering profession.

I.E.S. is not currently a member of the Engineers Joint Council.

Twin City Section Organizes Residence Lighting Forum

The organizational meeting of the new Residence Lighting Forum in the Twin City Section of I.E.S., was held February 21 at the Northern States Power Co. lunch room. Of the 42 members joining the Forum at this meeting, there are four interest decorators, eleven utility lighting representatives, nineteen electrical contractors or wholesalers, five fixture representatives and three builders.

Speakers at the meeting were Twin City Section Chairman Cecil Branham, who discussed "Why a Residence Lighting Forum," and L. E. Johnson, past chairman, who spoke on "The Future of Residential Lighting." A discussion period of almost an hour, following these presentations, indicated the high interest obtained.

Acting Chairman of the Forum is Richard White, Chairman of the Section's Residence Lighting Committee. Mrs. Marianne Battig is acting Secretary-Treasurer. Tom Earle, a member of the American Institute of Decorators, is publicity committee chairman.

Future plans for this year include April and May meetings.

Committee Personnel and National and Local Officers

Listing of the personnel of I.E.S. Committees — Standing, General, Task and Technical — begins on page 23A of this issue.

Officers of the Society and Local Representatives are listed beginning on page 37A.

Operation I.E.S.

Headquarters Staff Responsibilities

In last months edition we reviewed briefly the general operation and function of the Society's officers and committees (I.E., March 1956, p. 24A). To carry out the suggestions and recommendations of these committees and of Council, a permanent staff is maintained at Headquarters, with whom lie the final responsibility of the operation. A detailed analysis of all phases of the staff's work is hardly possible here, but a general idea of their operation may be of interest.

In the operation of the Society's affairs there are four separate divisions at Headquarters. Each of these is under the separate supervision of a Senior Staff member. These "departments" are:

General Office (Executive Secretary)
Technical Activities (Technical Director)
Publications, Editorial (Editor)
Publications, Advertising and Sales (Advertising and Promotion Manager)

The senior staff members having responsibility for these four activities coordinate the overall operation, of course, by cooperation and frequent consultation. The accompanying chart illustrates the four-department setup. The lines connecting from one department to the next indicate the close tie between these departments.

Each department has its own group of valuable assistants, also shown on the chart. As will be seen, the entire staff totals 18 people. Anyone aware of the vast amount of detail, correspondence, records, committee work, and publication production and distribution accomplished at I.E.S. Headquarters can well paraphrase Sir Winston and say "never has so much been done by so few." We are quite proud of the working staff at Society Headquarters.

Specific responsibility of each of the Senior Staff members may be of interest to the membership. Full details of their work would exceed our space here, but briefly their duties cover:

A. Dexter Hinckley — *Executive Secretary:*

Preparation of agenda, minutes and execution of actions taken by Council and Council Executive Committee.

Correspondence, records and report of and for Council, Council Executive Committee, Board of Examiners, Board of Fellows, Committee on Finance, Medal Award, Membership, Sustaining Membership, Regional Activities, National Technical Conference, Public Relations and Information, Procedures and Policies, Constitution and By-Laws, Board of Nomination, Committee of Tellers. All inquiries and correspondence on these subjects may be addressed to Dex Hinckley at Headquarters.

Assembly and editing of constituent parts of General Secretary's annual report, Guides, Manuals, Procedures and Policies, Constitution and By-Laws. Duplication, stock and distribution of these.

National Technical Conference, financial operation.

Headquarters Retirement Pension Plan, all records and correspondence.

Senior Staff coordination.

Coordination of maintenance and improvement of Headquarters facilities.

C. L. Crouch — *Technical Director:*

Works with technical committees to execute technical program. This includes attendance at technical committee meetings for consulting regarding policy, relationship to other Society pronouncements and reports, interchange of committee work, reviewing drafts of technical committee reports. Consultation with officers and committee chairmen on personnel for committee membership.

Works with other technical organizations to further the interests and progress of illuminating engineering. This includes negotiating for joint activities; processing of I.E.S. reports as American Standards; consultation and lectures; follow-up with I.E.S. representatives to other organizations.

Participates in I.E.S. Lighting Data Sheet Program, to certify that all represent illustrations of good practice in accordance with Society reports; obtain related data and prepare text.

Illuminating Engineering Research Institute, Secretary.

Ruby Redford — *Editor:*

Responsible for publication and production of all I.E.S. publications. This includes the monthly magazine Illuminating Engineering (except advertising pages), Lighting Handbook, Data Sheets, Recommended Practices and Standards, Committee Reports, etc. For IE it also includes details of procuring suitable material, planning editorial programs, writing articles, editing contributed material, rewriting contributed material where required. All correspondence related to the editorial phase of the Society's publications program may be addressed to Ruby Redford, and all manuscripts and other material submitted for possible publication should be sent to her.

Clayton E. Ellis — *Advertising and Promotion Manager:*

Responsible for advertising space sales for all I.E.S. publications: Illuminating Engineering, *I.E.S. Lighting Handbook.*

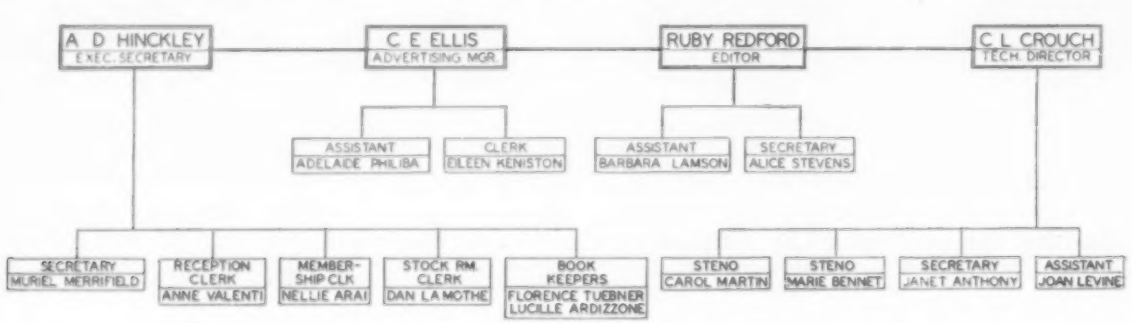
Advertising contracts and scheduling. Advertising layout and publication.

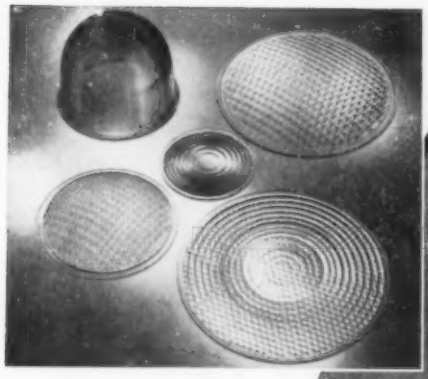
Publication Sales, in single copies and bulk, to members and non-members, including reprints of articles in IE, copies of American Standards and Recommended Practices, Committee Reports, Conference Preprints, etc.

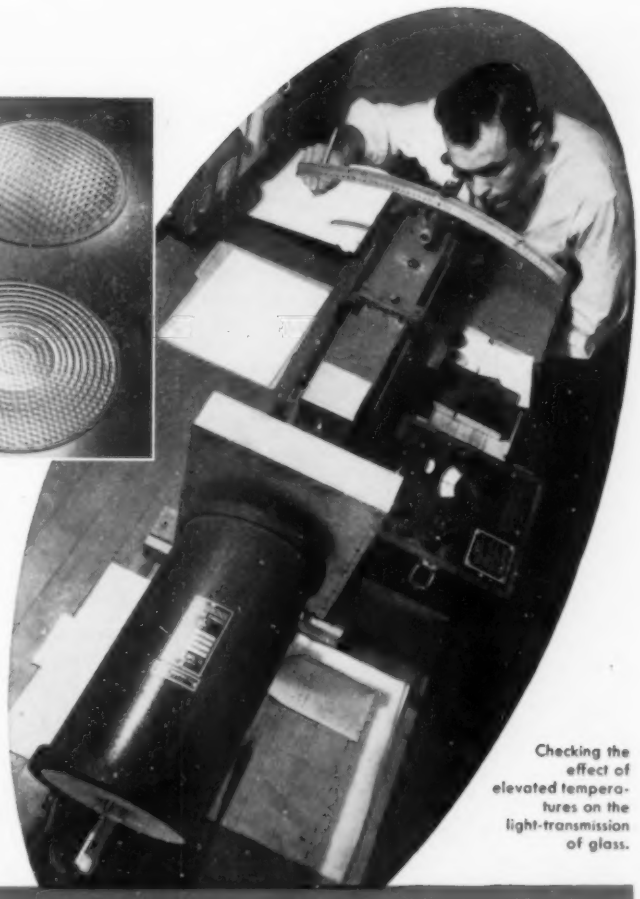
Non-member subscriptions to Illuminating Engineering.

Publications Sales activities in Sections and Chapters, including correspondence with Publications Sales Representatives and appropriate officers, sales helps and suggestions for Section and Chapter meetings. All promotional activities in connection with this, including displays,

(*Continued on page* 16A)







Checking the effect of elevated temperatures on the light-transmission of glass.

For
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BEAM CONTROL
and
COLOR TRANSMISSION

Specify **Kopp Lenses**

Various types and designs of signal lenses arranged for comparative examinations.

These characteristics in varying degrees and combinations are vitally important in applications of lighting and glassware. The knowledge and ability required to develop exact light distribution and color values takes years to obtain. Kopp offers you this technical background, plus highly-organized manufacturing skills, modern production methods, and a rigid inspection procedure. Regardless of whether your problem is simple or highly complex, our engineers will be glad to submit a design to do the job.

We'll be happy to have you put us to the test—without obligation.

KOPP GLASS

KOPP GLASS, Inc.

Swissvale, Pennsylvania

(*Continued from page 14A*)

mailing pieces, space advertising, sales letters.

Billing and collections for advertising and publications sales.

Because of the strong tie between internal and external operation of the Society, Senior Staff members generally attend Council meetings. As indicated in last month's chart, a close relationship exists between their operations and certain National Officers. The Executive Secretary, for instance, works closely with the General Secretary on the general operations of the Society. Similarly, the Technical Director and the Senior Vice-President are closely associated on technical operating aspects. The publications program is carried out under the scope of the Publications Committee, but here too there is a close connection with national officers; the Junior Vice-President serves as an executive liaison for publications matters.

Any Section or Chapter officer, or any member of the Society interested in further details of the operation of the four activities at Headquarters are invited to write directly to any of the Senior Staff members. — GEORGE J. TAYLOR, *General Secretary.*

JOINT meeting of the Western New York Section, I.E.S. and the Niagara Frontier Electrical Contractors Association was held February 8 at the Brounshidle Post, American Legion, Buffalo. Chairman W. E. Hayes conducts the meeting; Nate Pfeffer, Chairman of the Contractors group is at his right.

MEMBERS of the Western New York Section discuss the evening's topic, "A Look Ahead for Lighting," by Berlon C. Cooper, *Electrical Construction and Maintenance.* Left to right are: John Tylee, Lee Menteer, William McCarthy, Richard Skarin, Leon Kiersz and Joseph Kellas.

Wiring Design Course Co-Sponsored by Pittsburgh Groups

A series of twelve weekly meetings, which began February 27, co-sponsored by the Pittsburgh Section of I.E.S. and the Electric League of Western Pennsylvania, is covering the topic of Wiring Design.

The two-hour classes, which are held at the Duquesne Light Co. Cafeteria, cover the following subjects:

(1) Electrical Fundamentals
(2) Electrical Formulas
(3) Wiring Codes
(4) Electrical Conductors
(5) Electrical Systems
(6) Parts of Wiring System
(7) Wiring Materials
(8) Designing the Lighting Wiring System
(9) Residential Wiring
(10) Commercial Lighting Wiring
(11) Industrial Wiring
(12) Industrial Wiring, continued.

ABOUT PEOPLE

Lighting Products, Inc., Highland Park, Ill., announces the election of **Eric H. Church** to the newly established position as vice-president in charge of production. Mr. Church has been with Lighting Products since July of last year. He was formerly associated, for 24 years, with Benjamin Electric Mfg. Co.

Charles R. Pritchard has been elected a vice-president of the General Electric Co. Mr. Pritchard was formerly president and general manager of the General Electric Supply Co., a wholly-owned distributing organization which was merged into the parent company as a division in January. He will continue to serve as general manager of the division.

Dr. Joseph Slepian, associate director of the Westinghouse Research Laboratories, has retired after 40 years of service with Westinghouse. Dr. Slepian's contributions in the field of electric power total more than 250 patents, including his work in the development of high-speed methods of extinguishing arcs in electric power systems.

Micro Balancing, Inc., Garden City Park, N. Y., announces the appointment of **Michael Dingman** as sales manager to handle the company's line of photo-electric street lighting controls. Mr. Dingman was formerly sales representative for Pfaff & Kendall.

The appointment of **Cornelius J. Kelleher** to New England district sales manager, fluorescent fixtures, has been

(*Continued on page 19A*)

Standard Fixtures – Right out of the Catalog do this Interesting Lighting Job – by **LITECONTROL**

This handsome interior is the Franklin County Trust Company, Greenfield, Massachusetts. We think you'll agree that the Litecontrol lighting makes an important contribution to the pleasing appearance and we would like to tell you how it was accomplished — *with standard Litecontrol fixtures.*

Holophane Controlenses* keep the brightness subdued while distributing the light efficiently. Supplementary incandescent lens boxes are used in the rectangles, at all corners, and in the "tee" section where the fixture runs across the rectangle. Note how the lighting displays the murals to best advantage — from top to bottom.

We're specialists in supplying "the right light with the right fixture in the right place" . . . with a custom look at standard prices. Let us know your lighting requirements for stores, offices or public buildings.

* ℞ Holophane Co., Inc.

ARCHITECT: Howe, Prout & Ekman, Providence, R. I.

ELECTRICAL CONTRACTOR: Edward Stotz, Inc., Riverside-Gill, Massachusetts.

AREA: Public and Bank Working Sections.

CEILING HEIGHT: 12'-0".

FIXTURES: Litecontrol No. 5128 recessed lens troffers with No. 5100-33 corner type and No. 5100-35 tee type supplementary lens boxes in rectangle.

INTENSITY: 50-60 footcandles average in service.

LITECONTROL *Fixtures*

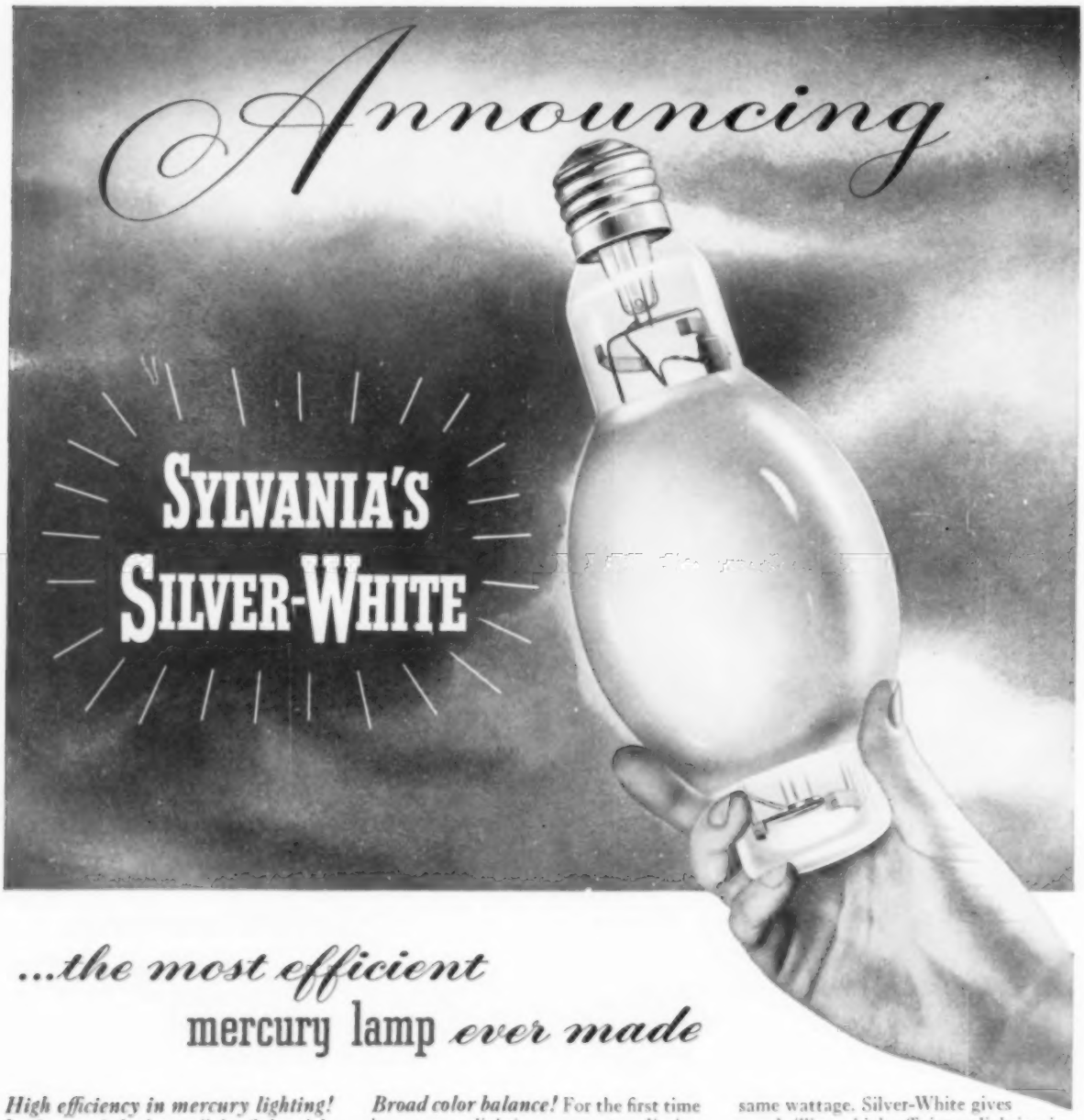
KEEP UPKEEP DOWN

LITECONTROL CORPORATION

36 PLEASANT STREET, WATERTOWN 72, MASSACHUSETTS

DESIGNERS, ENGINEERS AND MANUFACTURERS OF FLUORESCENT LIGHTING EQUIPMENT DISTRIBUTED ONLY THROUGH ACCREDITED WHOLESALERS

Announcing



...the most efficient mercury lamp *ever made*

High efficiency in mercury lighting! In the search for better light, Sylvania's scientists have developed new phosphors that enable the Silver-White mercury lamp to produce 10 to 20 per cent *more* light than clear mercury lamps.

The new phosphor in this bulb actually *adds* light, where previous "color improvements" subtracted from the light of the ordinary clear mercury lamp. The silver-white coating on this bulb diffuses and softens the tremendous light output. No other type of mercury lamp gives you so much light for your lighting dollar.

Broad color balance! For the first time in mercury lighting you get radiation across the whole width of the color spectrum.

Lighting costs are reduced! The 400-watt Silver-White mercury lamp gives on the average 7 times the burning hours of life as compared with incandescent of the same wattage.

Sylvania's Silver-White mercury lamps are now available in ratings of: 100-watt, 175-watt and two 400-watt types. They cost no more than other color-corrected mercury lamps of the same wattage. Silver-White gives you brilliant, high efficiency lighting in the factory, service station, parking lot, and in street and highway lighting.

Our commercial engineering department will be glad to help you with your special application or installation problems. For complete technical data write directly to:

SYLVANIA ELECTRIC PRODUCTS INC.
Lighting Division, Salem, Mass.
In Canada: Sylvania Electric (Canada) Ltd., University Tower Building, St. Catherine Street, Montreal, P. Q.

SYLVANIA®

... fastest growing name in sight

LIGHTING • RADIO • ELECTRONICS • TELEVISION • ATOMIC ENERGY

(Continued from page 16A)

announced by Sylvania Electric Products Inc., with offices at Loring Avenue in Salem, Mass. Mr. Kelleher joined Sylvania in 1944 and most recently has been assistant New England sales manager for lighting.

George S. Siegrist has been appointed vice-president of the Abolite Lighting Division of The Jones Metal Products Co., West Lafayette, Ohio. For the past two years Mr. Siegrist has been sales manager of Abolite, and prior to joining the company was associated with United Air Lines and Warner and Swasey Co.

North American Electric Lamp Co., St. Louis, Mo., announces new stockholders and officers of the company. These are: President and Treasurer, **Louis Lander;** Vice-President, **Edna Lander;** Secretary, **H. N. Adelstein.** These officers now own all the outstanding shares of the company.

Sylvania Electric Products Inc. announces the appointment of **Maurice V. Odquist** as director of new product sales, to work with the company's research laboratories and ten operating divisions in the creation, development and promotion of new products. Before joining Sylvania, Mr. Odquist was, most recently, a Vice-President and Director of C & C Super Corp., New York City.

The General Electric Research Laboratory's new European office now announces its permanent address at Pelikanstrasse 37, Zurich 1, Switzerland, with **Dr. George J. Szasz** as G-E's first scientific representative aboard. Now in Europe assisting Dr. Szasz in establishing the Zurich office is **Victor H. Fraenckel,** the Research Laboratory's consultant on scientific relations and director of the program under which the European liaison activity is being conducted.

William F. McChesney has been named Technical Assistant at International Business Machines Corp.'s Airborne Computer Laboratories. Mr. McChesney was formerly Illumination Engineer in Plant Engineering and Maintenance for IBM.

The appointment of **Elliot M. Nesvig** as General Sales Manager has been announced by Jefferson Electric Co., Bellwood, Ill. Mr. Nesvig was formerly with the General Electric Co.

"Standard" Available for Magnetic Recorded Film

A 400-cycle magnetic signal level test film, providing a reference for the level of magnetically recorded signal, is now available from the Society of Motion Picture and Television Engineers. This film will be used by the 16-mm equipment and sound recording industry as a basis for determining amplification, for frequency response calibration and for overall system evaluation of 16-mm magnetic recorders and reproducers.

The film is an original recording made on equipment of known good performance and calibrated against a "primary standard" sample produced by Frank H. Comerci, Robert Schwartz and Sheldon I. Wilpon in a research project for the Navy. It adheres to specifications defined by SMPTE's Magnetic Recording Subcommittee under the chairmanship of E. W. D'Arcy.

The track is 200 mils wide, recorded on the non-perforated edge of full-width coated film. The surface induction of the recorded signal is approximately 5 db below the maximum level obtainable at saturation of the type of magnetic coated film used. Nominal value of surface induction is 10.5 Gauss rms; average variation of the surface induction over the length of the film is ±0.5.

The film is available from SMPTE, 55 West 42nd St., New York 36, in lengths of 100 feet at $20.00, not including the New York City Sales Tax.

1956 Regional Conferences

Region	Place	Date
Pacific Northwest	Spokane, Washington Davenport Hotel	April 19-21
Inter-Mountain	Salt Lake City, Utah Utah Hotel	April 26-28
Great Lakes	Toledo, Ohio Commodore Perry Hotel	May 7-8
Midwestern	Indianapolis, Indiana Severin Hotel	May 10-11
Canadian	Quebec, Quebec Chateau Frontenac	May 17-18
East Central	Washington, D. C. Shoreham Hotel	May 24-25

NEW MEMBERS

At the meeting of the I.E.S. Council Executive Committee, held in New York, N. Y. on March 8, 1956, the following were elected to membership. Names marked * are transfers from Associate Member grade.

ALABAMA SECTION

Associate Members:

Claxton, N. E., Alabama Power Co., Birmingham, Ala.

Loeb, Ralph, Jr., Sherlock, Smith & Adams, Montgomery, Ala.

Montgomery, M. C., Cole Supply Co. Inc., Tuscaloosa, Ala.

ARIZONA SECTION

Associate Members:

Bradfield, Miss Dorothy M., Arizona Public Service Co., Phoenix, Ariz.

Kruger, Ruth D., Arizona Public Service Co., Phoenix, Ariz.

BLUENOSE CHAPTER

Associate Members:

Bell, A. K., Summerside Light & Power, Summerside, P.E.I.

Dunphy, G. H., Canadian General Electric Co. Ltd., Halifax, N. S.

Oakley, J. P., Donald C. Keddy, Ltd., Halifax, N. S.

BRITISH COLUMBIA SECTION

Associate Member:

Sambad, Myron, Hume & Rumble Ltd., Vancouver, B. C.

CENTRAL ILLINOIS CHAPTER

Member:

Tometich, W. H., Central Illinois Light Co., Pekin, Ill.

CENTRAL NEW YORK SECTION

Member:

*Haney, J. S., Crouse Hinds Co., Syracuse, N. Y.

Associate Members:

Buttimer, L. E., Niagara Mohawk Power Corp., Utica, N. Y.

Gaines, J. S., Niagara Mohawk Power Corp., Oneida, N. Y.

Morette, M. C., Niagara Mohawk Power Corp., Utica, N. Y.

Morris, B. J., Niagara Mohawk Power Corp., Utica, N. Y.

Niesen, J. R., General Electric Co., Syracuse, N. Y.

Reid, J. H., Niagara Mohawk Power Corp., Cortland, N. Y.

CENTRAL OKLAHOMA CHAPTER

Associate Members:

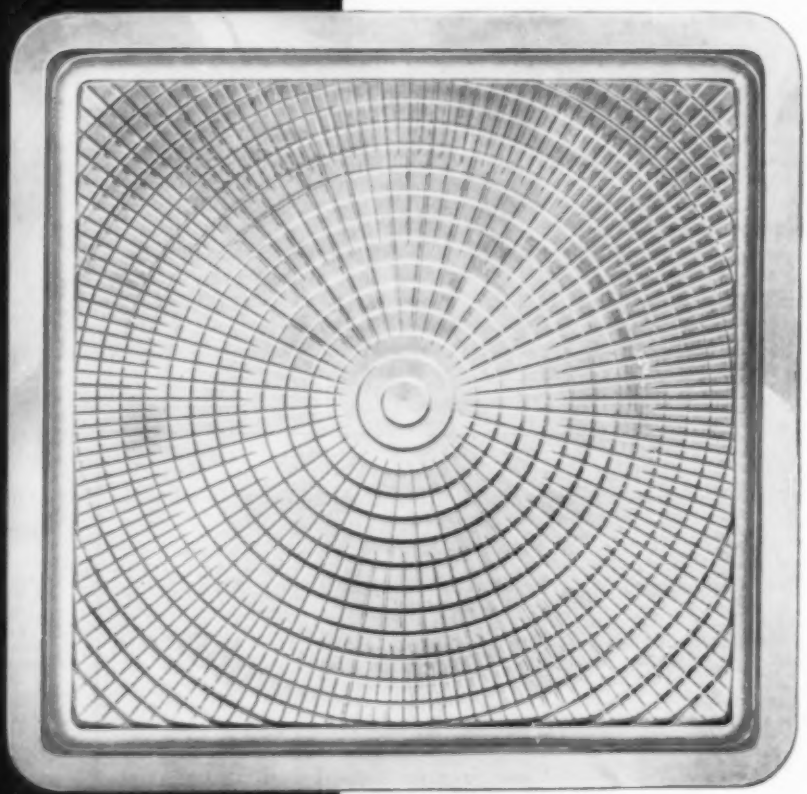
Foster, Stanley, Lightolier Co., Jersey City, N. J.

Hughes, A. C., Graybar Electric Co., Oklahoma City, Okla.

(Continued on page 48A)

amcoLens

the most exciting lens development in incandescent lighting



THE ART METAL COMPANY

CLEVELAND 3, OHIO

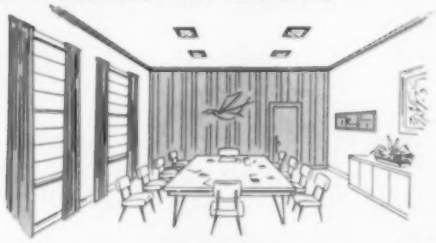
amcolens in industry

Designers of incandescent lighting for modern offices and executive suites have discovered a new tool, the Art Metal AMCOLENS. The AMCOLENS makes it possible to design incomparable efficiency as well as contemporary beauty into lighting systems. Installed in Art Metal recessed eliptisquares, AMCOLENS builds prestige among customers and employees. For dramatic, advanced lighting for conference rooms, lobbies, alcoves, reception rooms, lounges, offices and laboratories, AMCOLENSES are your contemporary keys to better lighting designs.

for OFFICES

AMCOLENS creates a cheerful office environment where employees enjoy working. Warm, colorful light is multiplied and directed to desks and cabinets by clear glass prisms, the most exact means known to science for controlling the direction of light.

for CONFERENCE ROOMS

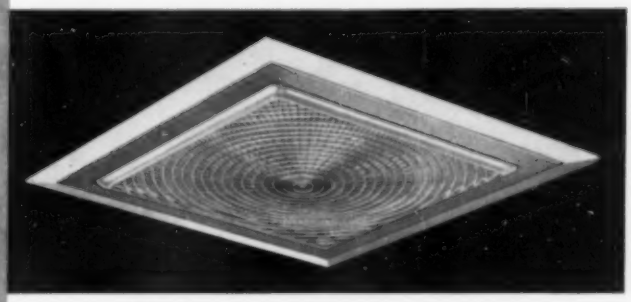


Handsome, deep AMCOLENSES provide diffused shadowless illumination and blend with the overall color scheme.

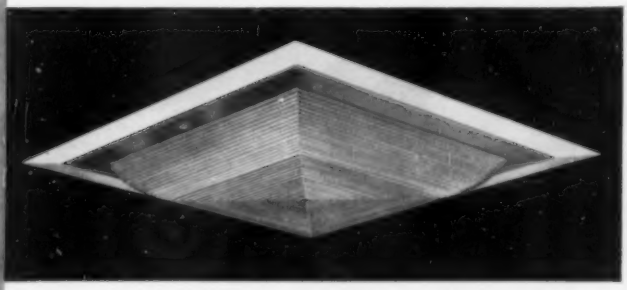
for LOBBIES

The rich subtle effect of the two-light deep AMCOLENS enhances the decor of any business gathering place. In terms of lighting efficiency and practicality, clear prismatic AMCOLENS has no equal.

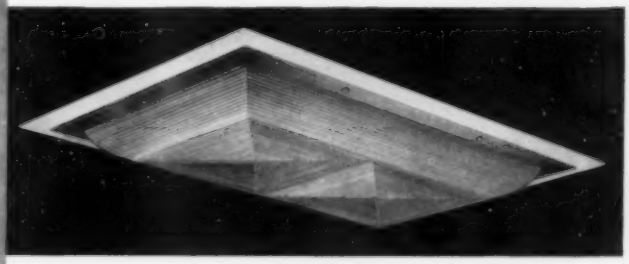
TYPES of recessed ELIPTISQUARES



Recessed Flush Eliptisquare—Four eliptisquare sizes accommodate 6½", 8½", 10⅜" and 12" AMCOLENSES. The eliptisquare reflector multiplies light output.



Deep Eliptisquare—Three sizes utilize 8½", 10⅜" and 12" AMCOLENSES.



Two Light Eliptisquare—Accommodates one 9½" x 16½" AMCOLENS which incorporates two symmetric lens elements each with its own lamp and eliptisquare reflector. All eliptisquare units have separate hinged doors which rotate open on two spring pin hinges.

AMCOLENSES ARE ANOTHER *Lighting Research* DEVELOPMENT OF ART METAL

THE **ART METAL** COMPANY

CLEVELAND 3, OHIO

Universal Ballasts
Proven Performers
of Certified Quality
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A complete quality line of fluorescent ballasts for Residential, Commercial and Industrial Applications.
Request our Catalog UMC-7-55 for helpful procurement data.
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UMC universal manufacturing corp.
35 East Sixth Street, Paterson 4, New Jersey

COMMITTEES

COMMITTEES
1955-1956

All committees are appointed by the President, subject to approval of the Council and, except as provided in the Constitution, terminate at the time of the first Council Meeing each administration, in the month of October. The scope of each committee is indicated.

R. F. Hartenstein, President, ex-officio member of all committees.

STANDING COMMITTEES

BOARD OF FELLOWS — To evaluate the eligibility of candidates for transfer to grade of Fellow according to procedures approved by the Council.

W. V. C. Foulks, Chairman, Curtis Lighting, Inc., 6135 W. 65th St., Chicago 38, Ill.

R. M. Evans — R. M. Love
S. G. Hibben — Roy A. Palmer
George E. Shoemaker

COUNCIL EXECUTIVE — To conduct the affairs of the Society between Council meetings.

R. F. Hartenstein, Chairman, Ohio Edison Company, Akron 8, Ohio.

K. M. Reid — G. J. Taylor
J. S. Schuchert — M. N. Waterman

FINANCE — To have direct supervision of the financial affairs of the Society and to present to the Council an annual report on its financial condition. To make recommendations to the Council as to the investment of moneys and upon all specific appropriations. To prepare and submit for approval of Council not later than the October meeting a budget of income and expense for the ensuing fiscal year.

W. W. Booth, Chairman, General Electric Supply Corp., 1260 Boston Ave., Bridgeport 8, Conn.

C. C. Keller — J. S. Schuchert, ex-officio
W. P. Lowell, Jr. — R. M. Zabel

GENERAL BOARD OF EXAMINERS — To investigate the qualifications of all applicants for admission to membership; to elect or reject applicants for the grade of Associate Member and Student Member, to report such action to the Council; and to make recommendation to the Council regarding applications for transfer or election to the grade of Member and for transfer to the grade of Member Emeritus.

Svend W. Bruun, Chairman, Rambusch Decorating Co., 40 W. 13th St., New York 11, N. Y.

H. E. D'Andrade — Ralph MacVean

MEDAL AWARD — To evaluate the eligibility of candidates for award of the I.E.S. Medal according to procedures approved by the Council.

Ward Harrison, Chairman, 23475 Stanford Road, Cleveland 22, Ohio.

Berlon Cooper — D. M. Jones
G. F. Dean — A. H. Manwaring
C. H. Goddard — E. M. Strong
B. J. Jensen — L. E. Tayler

PAPERS — To procure, review and approve all technical papers and discussions thereof, for presentation before National Conferences of the Society.

H. F. Davidson, Chairman, Hydro-Electric Power Commission of Ontario, 620 University Ave., Toronto, Ont., Canada.

L. E. Barbrow — E. F. Lowry
B. S. Benson, Jr. — Floyd W. Sell
B. F. Greene — G. A. Trosper
S. K. Guth — H. L. Wright
R. M. Zabel

PUBLICATIONS — To be responsible for the procurement, review and approval of all material for the publications of the Society other than technical papers approved by the Papers Committee for presentation at National Conferences of the Society and their discussions and committee reports, for which it will have publication responsibility only. Shall also be responsible for the editing, printing and business management of the publications of the Society; specific exceptions may be made by Council.

J. S. Schuchert, Chairman, Duquesne Light Co., 435 Sixth Ave., Pittsburgh 19, Pa.

Brooks Chassaing — R. W. Morris
H. F. Davidson — Aileen Page
J. A. Schneller

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James Finn — E. V. Manser
A. R. Hampsey — G. L. Morris
Ray Jonas — Ruth Patterson
R. Wylie

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C. W. Whitmore

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R. M. Zabel, Vice-Chairman, Westinghouse Electric Corp., Bloomfield, N. J.

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B. S. Benson, Jr. — Floyd W. Sell
L. J. Buttolph — G. A. Trosper
B. F. Greene — H. L. Wright

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Brooks Chassaing, Chairman, Art Metal Company, 911 Locust St., St. Louis 1, Missouri.

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W. P. McPherson — R. E. Wingfield
H. D. Mosley — William Winglar
R. E. Wozniak

Subcommittee on Technical Data Sheets

J. A. Schneller, Chairman, Lighting Products, Inc., 1549 Park Ave., W. Highland Park, Ill.
George T. Anderson, Jr., Vice-Chairman, Philadelphia Electric Co., 1015 Chestnut St., Philadelphia, Pa.

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Elmer Brigham — L. L. Nurnberger
C. H. Bronner — C. E. O'Daniel
Harrison Burrall — R. A. Reynolds
L. Ralph Bush — Randall H. Rice
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Fred Dunn — D. N. Schneider
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R. H. Fell — Louis Stout
W. J. Flynn — Nick Stuffer
J. M. Foreman, Jr. — S. J. Sumner
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M. G. Herbert — Neil Thompson
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W. B. Kennedy — Marvin Westrick
W. T. Kimery — C. W. Whitmore
Norman Kridel — C. Q. Wiggins
Chester Kuzniar — William C. Young
A. G. Zitelli

Subcommittee on Home Lighting Data Sheets

Aileen Page, Chairman, General Electric Co., Nela Park, Cleveland 12, Ohio.

GENERAL COMMITTEES

ADVANCE PLANNING — To study the operation, program, publication activities, membership classifications and financial structure with a view of its immediate and long-range objectives and to make recommendations to Council.

F. C. Winkler, Chairman, Westinghouse Electric Corp., 1216 W. 58th St., Cleveland 1, Ohio.

G. W. Beals — Glenn E. Parks
A. H. Clarke — E. M. Strong
B. J. Jensen — L. C. Twichell
W. P. Lowell, Jr. — J. F. Whitehead, Jr.
R. M. Zabel

ADVISORY BOARD TO THE PRESIDENT — To examine the organization, accomplishments, and assignments of committees and prepare not later than July 1st of each year a proposed list of committees and personnel; and to evaluate costs and benefits of present and proposed Society services.
M. N. Waterman, Chairman, Westinghouse Electric Corp., Bloomfield, N. J.
G. W. Beals — D. M. Jones
C. L. Crouch — K. M. Reid
A. D. Hinckley — F. C. Winkler

ALLIED ARTS — To encourage and assist local competitions in allied arts, in cooperation with technical committees and interested local groups.
Karl A. Staley, Chairman, General Electric Co., Nela Park, Cleveland 12, Ohio.
C. A. Atherton — Kenneth Parsons
Douglas H. Baker — R. C. Putnam
Robert W. Brown — Frank G. Reed
T. J. Killian — W. D. Riddle
Malcolm E. Lien — John A. Russell
Onnie Mankki — Laurence Schmeckebier
Joseph McCullough — G. E. Shoemaker
Eldon Winkler

BOARD OF NOMINATION — To prepare a nomination ticket containing the names of those who are deemed best suited to serve as officers and directors in positions to be filled at the ensuing election
E. M. Strong, Chairman, Cornell University, Ithaca, N. Y.
D. M. Jones — A. H. Manwaring

Regional Representative	Alternate
Joseph Thomas	G. F. Dean
Nelson C. Warner	G. W. Wagner
W. A. Stannard	John E. Dawson
James R. Chambers	B. S. Benson, Jr.
C. W. McCormick	B. J. Jensen
Blair E. Plowman	———
J. D. Mitchell	G. L. Morris
J. G. Felton, Jr.	J. D. Whitnell
J. D. Whitnell	———

CONSTITUTION AND BY-LAWS — To prepare for Council proposed amendments to the Constitution.
G. F. Dean, Chairman, Toronto Hydro-Electric System, 14 Carlton St., Toronto, Ont., Canada.
Arvid S. Almryde — R. G. Slauer
J. B. Browder — Walter Sturrock

COORDINATING COMMITTEE FOR DEFENSE— To contact various Government Agencies concerned with National Security suggesting cooperation and participation in specific projects as an aid to solution of their problems. Recommending the placement of lighting study projects in present committees or the appointment of study project committees to the Society President and to expedite such study projects and guide accepted reports into proper Government channels.
A. F. Wakefield, Co-Chairman, The Wakefield Company, Vermilion, Ohio.
J. W. Bateman, Co-Chairman, Canadian General Electric Co., Toronto, Ont.
H. R. Blackwell — C. L. Crouch
R. B. Brown, Jr. — K. M. Reid
O. P. Cleaver — John S. Walsh
M. N. Waterman

HISTORICAL — To assemble and make available for current reference and to prepare in suitable and durable form for posterity, such historical facts, printed memorabilia, photographs, voice records, museum specimens and allied items as may be judged worthy of composing a continuing digest of the record of the Society's history.
S. G. Hibben, Chairman, 31 Clinton Avenue, Montclair, New Jersey.
R. B. Burton, Sr. — C. A. B. Halvorson
Julius Daniels — H. L. Logan
Leo Dolkart — J. L. Stair
G. H. Stickney

LIGHTING SERVICE — To stimulate and promote the discussion and practical application of lighting recommendations and to conduct a Lighting Service Forum in connection with the National Technical Conference.
L. E. Taylor, Chairman, The Detroit Edison Co., 2000 Second Ave., Detroit 26, Michigan.
Roy Dahlin — T. C. Sargent
R. C. Paslay — J. E. Sweatte
Joseph Thomas

MEMBERSHIP — To develop plans and supervise the operation of the individual membership activity of the Society.
W. A. Stannard, Chairman, Consumers Power Co., 212 W. Michigan Ave., Jackscon, Mich.
Fred Arady — W. J. Montabone
Francis Clarke — G. L. Morris
J. S. Frizzell — Charles Selby

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E. S. Goldman — F. Earl Webb

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L. C. Crabtree — Earl Pond, Jr.
V. W. Diak — Elmer Prag
Roland B. Dygert — M. E. Price
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J. S. Frizzell — I. Newton Raney
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Clifford D. Ham — Hugh X. Sheeter
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W. Holtsinger — A. H. Stevenson, Jr.
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A. J. Kurtzon — A. D. Wallace
Emile Landriault — M. R. Weiman
Georges Langlais — Richard S. Wissoker
P. J. Lepore — Jack C. Wright
Howard Long — O. Reynolds Young

NATIONAL TECHNICAL CONFERENCE — To be completely responsible, subject to the approval of Council, for the general coordination of all conference activities, for selecting and recommending time and place for review of the plans and budgets of the National Technical Conference Executive Committee and in cooperation with the Papers Committee for the satisfactory time allocation for the Technical Papers sessions according to Procedures and Policies as adopted by Council.
J. C. Forbes, Chairman, General Electric Co., Nela Park, Cleveland 12, Ohio.
C. L. Amick — C. N. Laupp
W. W. Booth — C. W. McCormick
J. B. Browder — J. D. Mitchell
R. B. Brown, Jr. — John Ruffatto
H. F. Davidson — C. C. Shotwell
Clare K. Fulton — L. E. Tayler
A. D. Hinckley — Joseph Thomas

1956 Conference Executive Committee
R. B. Brown, Jr., Chairman, Boston Edison Co., 39 Boylston St., Boston 12, Mass.
R. G. Slauer — R. F. Townsend
N. E. Tiebhurst — F. J. Vorlander
R. W. Wilson

PROCEDURES AND POLICIES—To study problems of Society procedure and policy referred to the Committee by Council, and to formulate recommendations to Council for the statement, revision, or clarification of these procedures and policies consistent with the Constitution and By-Laws of the Society.
G. W. Beals, Chairman, The Miller Co., Meriden, Conn.
Brooks Chassaing — W. A. Stannard
G. F. Dean — L. C. Twichell
C. C. Shotwell — J. S. Walsh
F. C. Winkler

PUBLIC RELATIONS AND INFORMATION — To prepare and disseminate information about the activities, accomplishments, programs, objectives and policies of the Society and about the place of illuminating engineering in modern society; to formulate and submit public relations policies and plans for the Society.
J. F. Whitehead, Jr., Chairman, Day-Brite Lighting Inc., 5411 Bulwer Ave., St. Louis 7, Mo.
W. L. Byrne — F. E. Guth
A. H. Clarke — S. H. Hazleton
B. C. Cooper — R. M. Johannesen
W. A. Dalrymple — W. A. Stannard

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M. G. Herbert — Edward Watt
H. G. Hrivnatz — J. A. Watt
J. Hughes — G. A. Watters
James H. Hull — R. E. Wingfield
William Winglar

REGIONAL ACTIVITIES — To represent the respective Regions before the Council and to keep the Council informed regarding the affairs of the Regions. To stimulate Society activities, to encourage joint meetings of Sections and Chapters including Regional Conferences within the respective Regions and to promote the expansion of the Society.
K. M. Reid, Chairman, General Electric Co., Nela Park, Cleveland 12, Ohio.
James R. Chambers — Blair E. Plowman
John G. Felton, Jr. — A. C. Sangster
Dan M. Finch — Joseph Thomas
C. W. McCormick — Nelson C. Warner
J. Dixon Mitchell — J. D. Whitnell
Southern Region, Assistant to Regional Vice-President, George L. Morris.

RESIDENCE LIGHTING FORUMS — To stimulate and assist the Residence Lighting Forums of the Society and to encourage the formation of additional Forums. To conduct a Residence Lighting Forum in connection with the National Technical Conference.
Ruth Morris, Chairman, Georgia Power Company, P. O. Box 1719, Atlanta, 1, Georgia.
Lillian Eddy — Buford Martin
Eve Freyer — Elizabeth Parker
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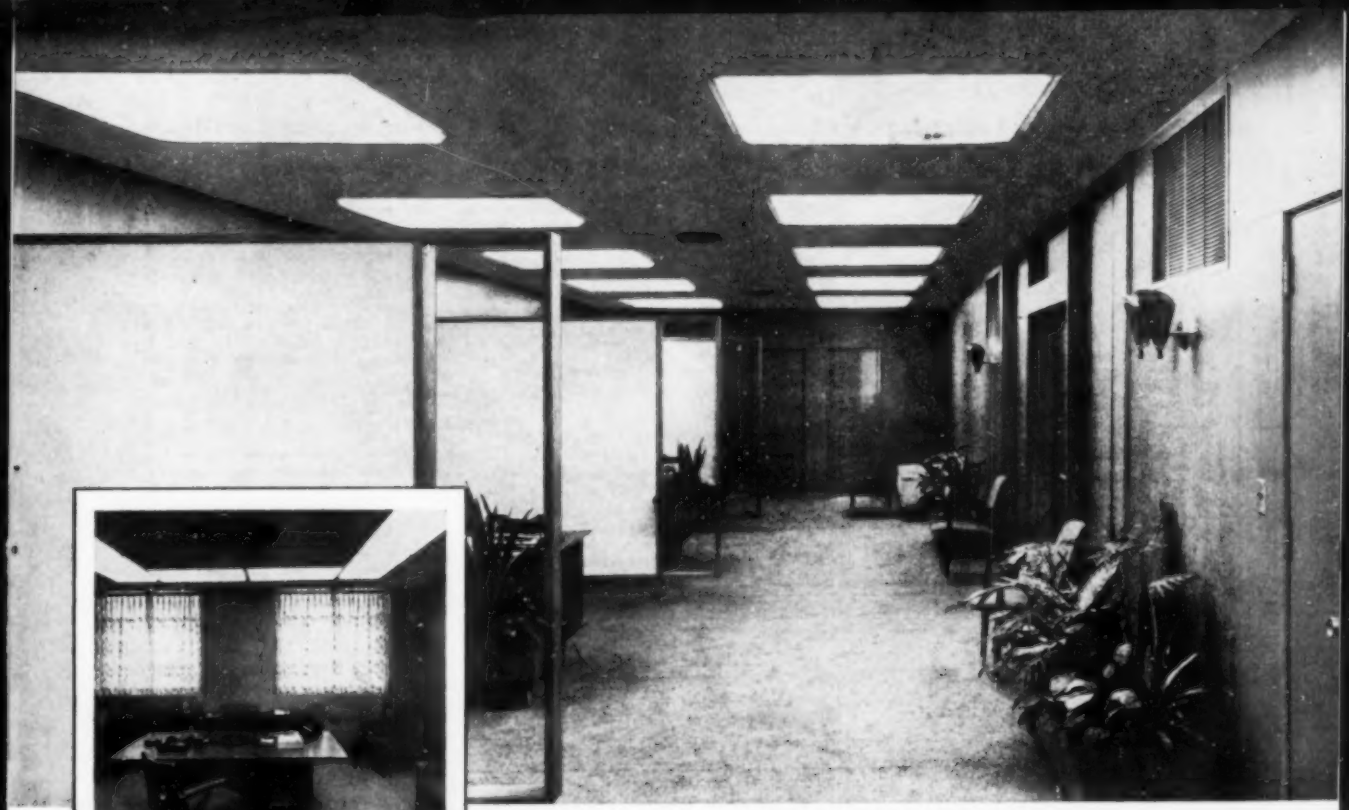
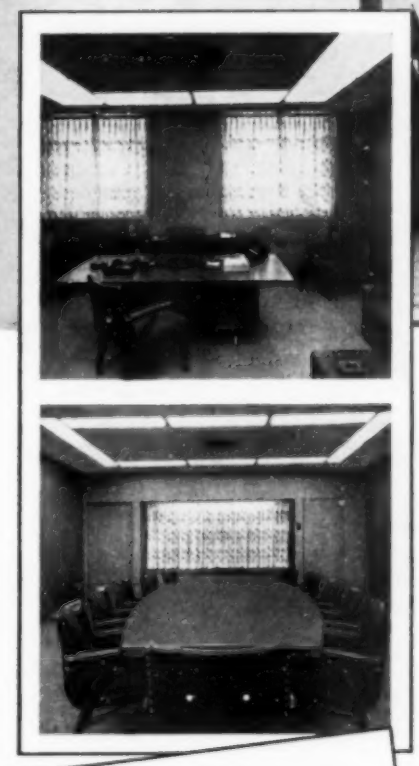
(Continued on page 26A)





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(*Continued from page* 24A)

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Revision of "Recommended Practice of Daylighting"

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O. C. Lange, Chairman, Pennsylvania Power & Light Co., 9th & Hamilton Sts., Allentown, Pa.
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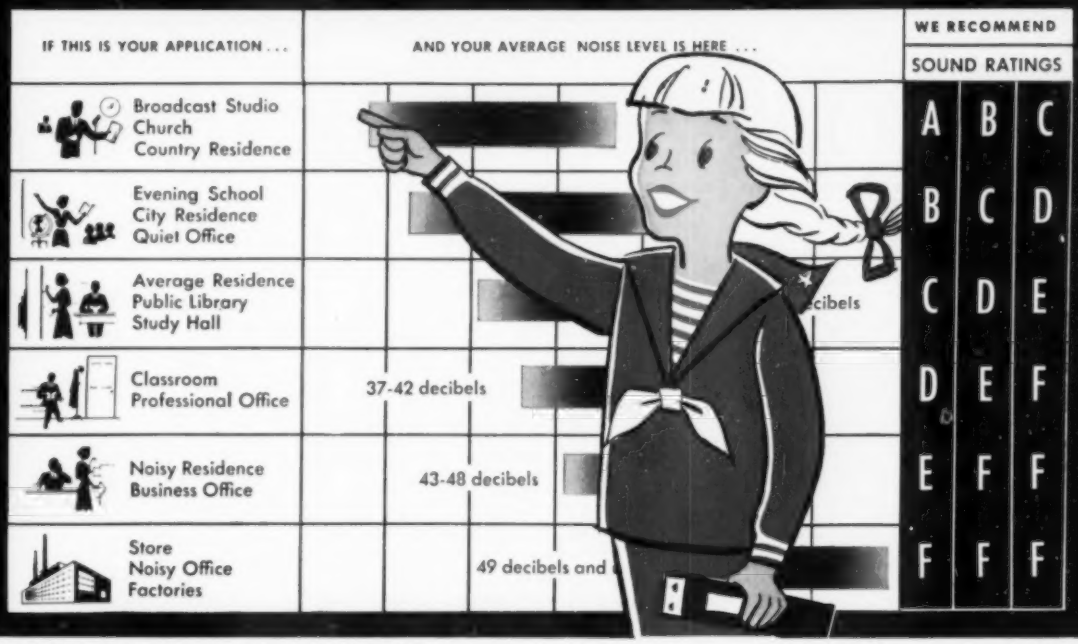
(*Continued on page* 28A)



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*Miss Fluorescent Ballast, G.E.'s Ballast Mascot.

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(*Continued from page 26A*)

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John Keyes	P. S. Schmidt

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LIGHT SOURCES — To correlate and report available information as to the physics of light and light production and the characteristics of current light sources.

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Color Rendition

Dorothy Nickerson, Chairman, 2039 New Hampshire Ave. N. W., Washington 9, D. C.

LIGHTING DESIGN PRACTICE — To study published data on coefficients of utilization, room indexes, maintenance coefficients and other elements entering into calculations for lighting design; develop standard methods for use in Society publications and report thereon.

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R. S. Wiseman, Vice-Chairman, c/o Engineer Research & Development Laboratories, Fort Belvoir, Va.

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Curriculum

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L. H. Brown	R. C. Putnam
W. A. Hedrich	R. S. Wiseman

Revision of "Experiments with Light"

A. A. Eastman, Chairman, General Electric Co., Nela Park, Cleveland, Ohio.

W. H. Billharts	R. D. Burnham

Preparation of Brochure "Careers in Illuminating Engineering"

R. S. Wiseman, Chairman, c/o Engineer Research & Development Laboratories, Fort Belvoir, Va.

D. M. Finch	R. W. McKinley

E. M. Strong

LIGHTING MAINTENANCE — To study the elements contributing to maintenance factors; set up the framework of typical field studies to determine factors; and to stimulate the prosecution of such studies by appropriate agencies.

R. L. Zahour, Chairman, Westinghouse Electric Corp., Bloomfield, N. J.

F. Clark, Vice-Chairman, Lighting Services, 515 Meridan Rd., Waterbury, Conn.

M. E. Keck, Secretary, Westinghouse Electric Corp., 1216 W. 58th St., Cleveland, Ohio.

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MOTOR VEHICLE LIGHTING (EXTERIOR) — To study the problems of illuminating the night operations of motor vehicles and to make suitable recommendations for promoting maximum safety and convenience including accessory illuminated signal and traffic aids.

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NOMENCLATURE — To define the terms and standards of illumination, and endeavor to obtain uniformity in nomenclature.

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C. L. Cottrell	W. W. Menke

Harris Reinhardt

OFFICE — To study the lighting requirements of office lighting tasks, develop suitable lighting recommendations and report thereon.

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G. F. Dean, Vice-Chairman, Toronto Hydro-Electric System, 14 Carlton St., Toronto, Ont., Canada.

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PROGRESS — To keep in touch with developments in the art of lighting throughout the world and prepare a yearly review of achievements in the art of illuminating engineering for inclusion in ILLUMINATING ENGINEERING.

James H. McCulloch, Chairman, Independent Testing Laboratories, Boulder, Colo.

Ward Harrison, Honorary Chairman, 23475 Stanford Road, Cleveland, Ohio.

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PUBLIC CONVEYANCES — INTERIOR LIGHTING — To study the application of light to all public areas in conveyances used for passenger transportation, including particularly trains, buses, ships, street railways and subways, and report thereon.

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J. B. Feder	R. L. Sweeney
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A. F. Vandevelde

RESIDENCE — To study and report on the application of light and lighting in residences; to develop performance recommendations for residence luminaires and to prepare necessary educational aids.

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Mary E. Dodds — Elizabeth A. Meehan
Myrtle Fahsbender — Jan Reynolds
E. W. Halteman — R. V. Smith
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Mary Taepke, Chairman, Detroit Edison Co., 2000 Second Ave., Detroit, Mich.

Mary Dodds — Evelyn Hansen
Marguerite Fenner — Elizabeth Meehan
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Portable Lamps—Measurement of Performance Characteristics

E. W. Halteman, Chairman, Pennsylvania Power & Light Co., 534 Main St., Bethlehem, Pa.

Arthur Jaeger — Priscilla Presbrey
Kaye Leighton — Jan Reynolds

Revision of "Contemporary Lighting for Modern & Traditional Interiors"

M. Fahsbender, Chairman, Westinghouse Electric Corp., Bloomfield, N. J.

Kaye Leighton — Gladys Miller
Jan Reynolds

SCHOOL — To study the application of light and lighting to the spaces and processes involved in educational institutions and to report thereon.

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C. J. Allen, Secretary, General Electric Co., Nela Park, Cleveland, Ohio.

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R. D. Bradley — C. N. Laupp
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R. C. Hultgren — H. A. Stroud
L. V. James — John Walsh
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SEARCHLIGHT — To study the design and application of searchlights and to report thereon.

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Thomas Cushing, Secretary, Hanovia Chemical & Mfg. Co., 100 Barr Bldg., Washington, D. C.

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SPORTS AND RECREATIONAL AREA LIGHTING — To develop current recommended practices for lighting sports and recreational areas; study techniques of application including effects on player performance and spectator visibility and report thereon.

F. D. Wyatt, Chairman, 1435 Catalpa Ave., Chicago, Ill.

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J. J. Neidhart, Vice-Chairman, Westinghouse Electric Corp., 1216 W. 58th St., Cleveland Ohio.

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(Continued on page 32A)

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* See LIGHTING – December 1955

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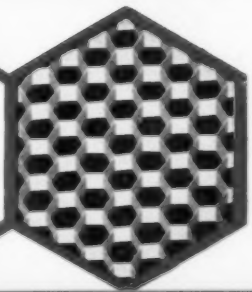

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(*Continued from page 30A*)

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Lighting Practices

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(*Continued on page 37A*)

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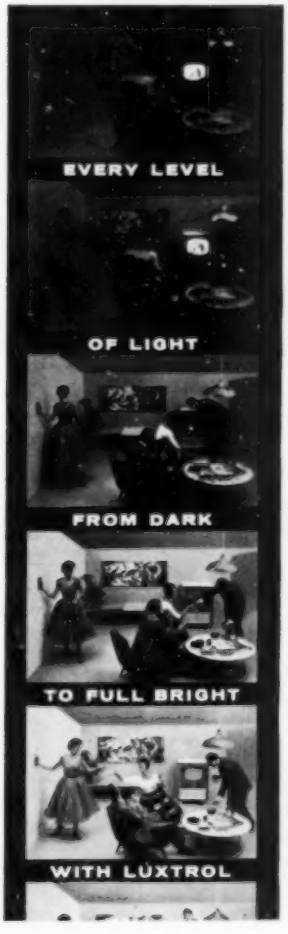

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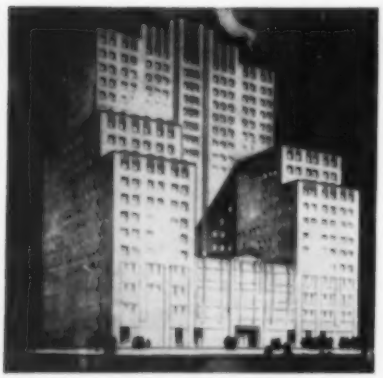

Commonwealth Life Insurance Co.,
Louisville, Kentucky
Engineers: Stevenson Engineering Co.
Fixtures: Holdenline Co.

McColl-Frontenac Oil Co. Ltd.,
Montreal, Que.
Architects: Barott, Marshall,
Montgomery and Merrett
Fixtures: Curtis Lighting of Canada

Police Facilities Building,
Los Angeles, Calif.
Architects: Welton Becket, F.A.I.A., and
Associates and J. E. Stanton, A.I.A.,
Associated Architects
Fixtures: Columbia Electric and Mfg. Co.

Socony-Mobil Building, New York
Owner: Galbreath Corporation
Architects: Harrison & Abramovitz, John B. Peterkin
Fixtures: Ruby-Philite Corp.

Amoco Building, New York
Architects: Emery Roth & Sons
Fixtures: Eastern Lighting Products

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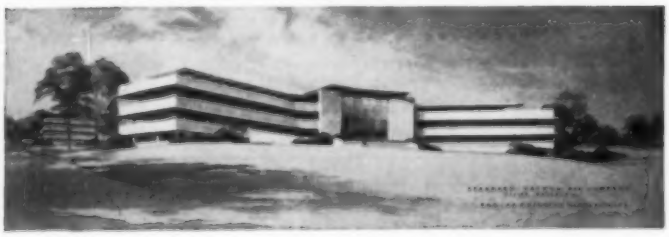
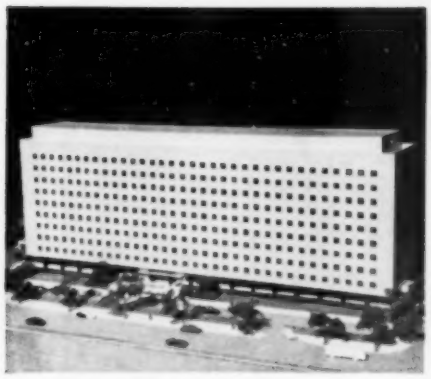
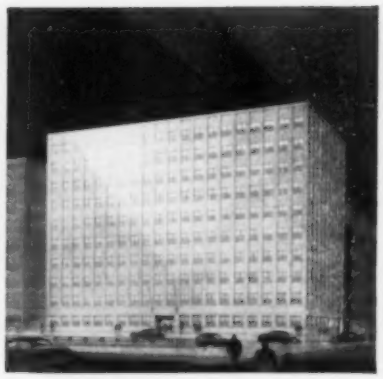


Standard Vacuum Building, Harrison, N. Y.
Architects: Eggers and Higgins
Fixtures: Fullerton Manufacturing Co.



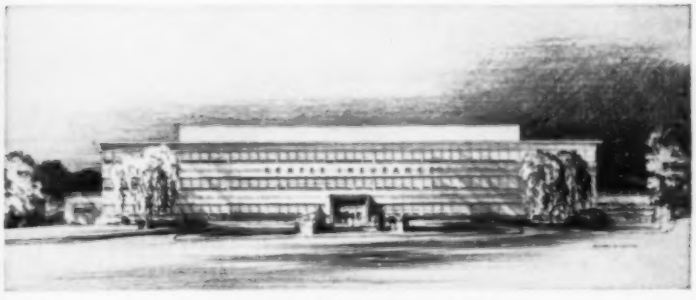
General State Authority
Health and Welfare Building,
Harrisburg, Pa.
Architects: Lacy, Atherton & Davis
Fixtures: Smithcraft Lighting

United States Rubber Co. Building
Addition, New York
Architects: Harrison & Abramovitz
Fixtures: Globe Lighting Products Inc.



Sinclair Oil Building, Chicago
Owner: John W. Galbreath & Co., Inc.
Architects: Holabird & Root & Burgee
Fixtures: Day-Brite Lighting Co.

City-County Building, Detroit
Architects: Harley, Ellington & Davis Inc.
Fixtures: Fullerton Manufacturing Co.



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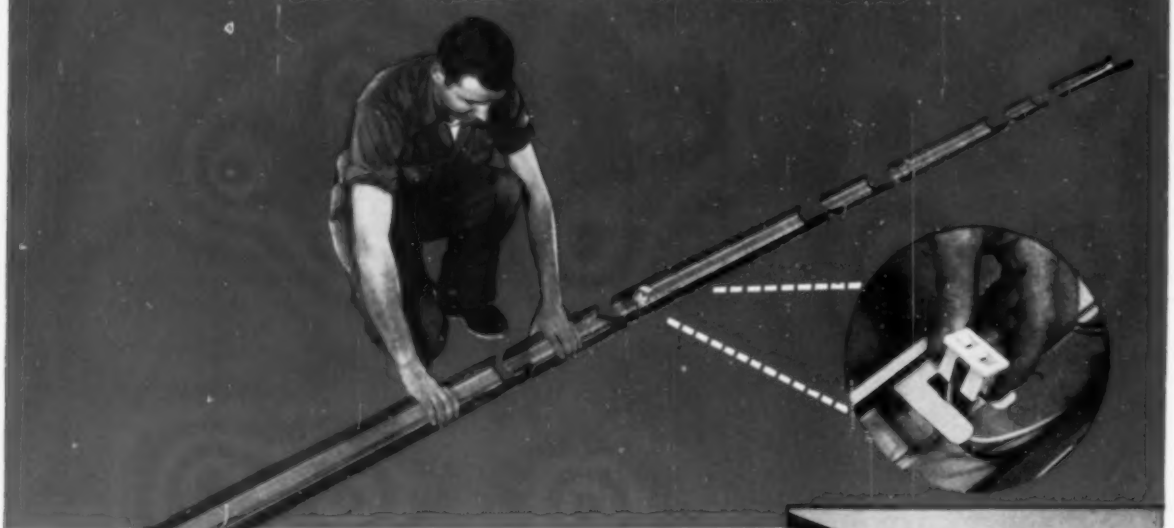

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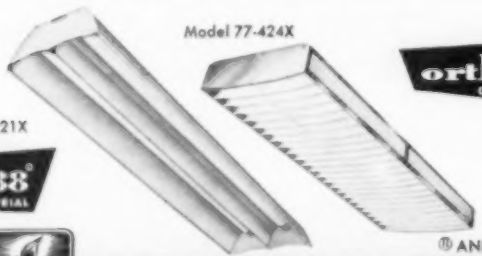

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Centerville, Iowa — Paul Anderson, Iowa Southern Utilities Co.
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(Continued on page 42A)

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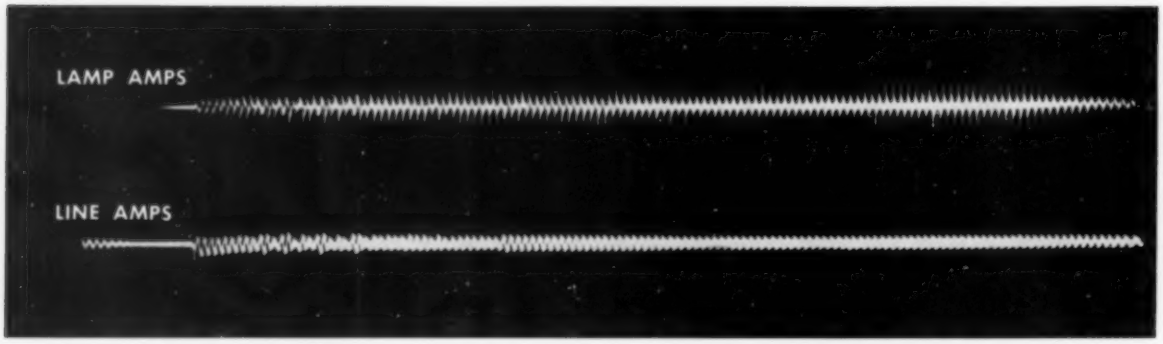
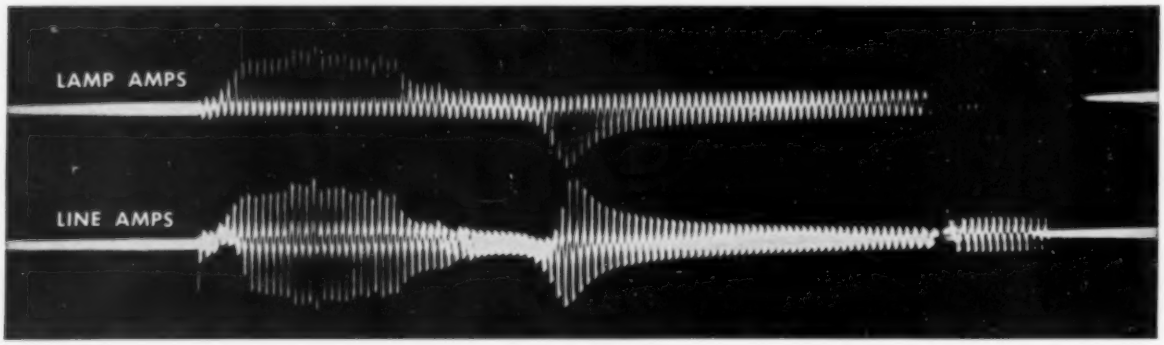


COMPARISON OF STARTING CHARACTERISTICS for regulated and unregulated mercury vapor lamp ballasts shows (above) 400w E-H1 mercury vapor lamp with Sola Ballast Cat. No. 77034 and (below) the same lamp with conventional non-regulating ballast. Comparison illustrates Sola's current-limiting characteristic, an advantage of its constant wattage circuit.



Sola Constant Wattage Mercury Vapor Ballasts Limit Starting Surge, Extend System Capacity

In addition to regulated lumen output, the Sola Constant Wattage Circuit also yields other important advantages. Starting characteristics are an important example. Sola Constant Wattage Mercury Vapor Lamp Transformers limit line current surge at the instant of starting to effectively no more than normal full load value. This eliminates the need for time-delay relays, oversize circuit breakers, and heavier wiring required by the starting characteristics of conventional, non-regulating transformers.

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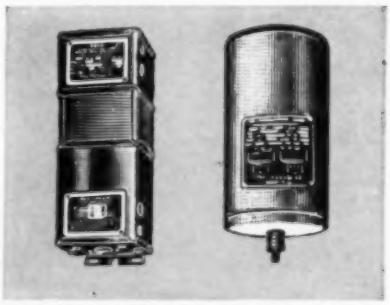
- Stabilized light output within $\pm 2\frac{1}{2}\%$ with line variations as great as $\pm 13\%$.
- Lamps stay lit, even when line voltage drops as much as 40v (on a 115v line).
- Positive starting within the primary ranges of 100-130 x 200-260v.
- Elimination of primary taps.
- Primary current limited on both open and short circuit.
- More ballasts can be installed per circuit.

For further information, call your Sola representative.



Sola Mercury Vapor Lamp Transformers, employing the patented constant wattage circuit, are available for indoor (left) and outdoor (right) industrial and commercial applications. The moderate differential in original cost, over non-regulating ballasts, is often eliminated by installation savings and by continuous high quality performance.

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Special packet of ten new home lighting data sheets, showing modern lighting for new and remodelled kitchen and bathroom areas; an important addition to any home lighting idea library. (These sheets are not included in an annual Series.)

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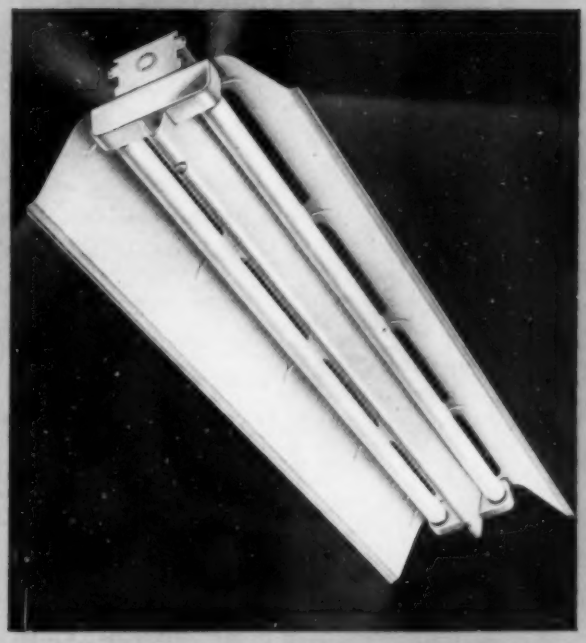

The Diamond-"I"—New Sylvania semi-direct fixture has 25% upward light component. Extremely high 89% illumination efficiency. Captive bolt arrangement simplifies installation and maintenance. Meets or exceeds all new RLM specifications.

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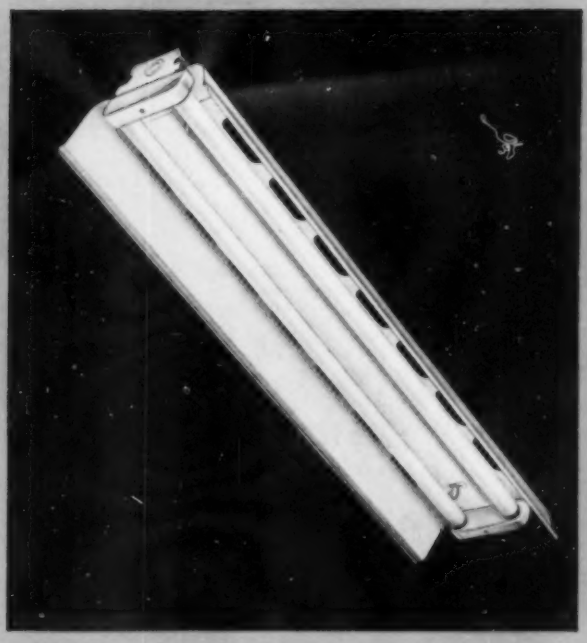
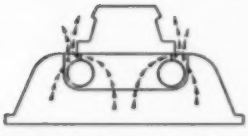


NTWS Series—Complete Sylvania semi-direct series for many industrial applications. Features 10% upward light component, extremely high efficiency. Available with closed or open-end reflectors. RLM approved.

WHICH DOES YOUR PLANT NEED?



Reflector slots in Sylvania semi-direct fixtures create a "chimney effect" of rising air which dissipates lamp heat, carries away dust and dirt from lamps and reflectors, allowing lamps to operate at peak efficiency.

PERHAPS *your* plant would benefit from new lighting equipment which directs a full 25% of its light *up!*

Sylvania's outstanding new Diamond-"I" fixture answers industry's need for more *upward* light and reduction of eye-straining overhead contrasts, delivers more and better light at working level. It's the fixture which meets or exceeds all new RLM specifications for fixtures with greater upward components of light. And it has an extremely high illumination efficiency of 89%.

Or, if preferred, Sylvania's complete line of NTWS fixtures will fill the bill for applications using 10% upward light.

Whichever of these Sylvania fixtures suits your needs—Diamond-"I" or NTWS—you can be sure of getting lowest maintenance cost with either. On both types, one man can easily change lamps. Reflectors on both series are always 4 feet long—on both the 4- and the 8-foot units.

The Sylvania lighting specialist in your area will gladly discuss your lighting problems with you. The coupon below will bring you complete technical data.

SEND FOR HELPFUL TECHNICAL DATA

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☐ Please send me information on your industrial fixtures.
☐ Have a Sylvania lighting specialist call on me.

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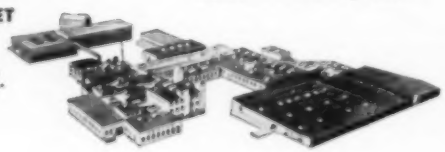

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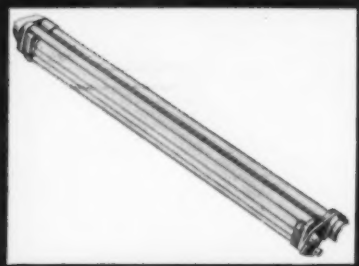
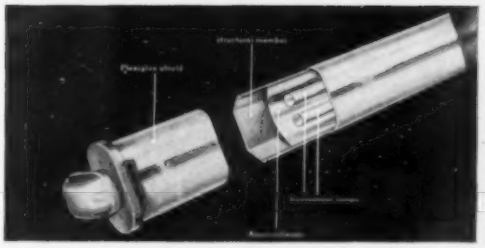
(*Continued from page* 51A)

The difference between needing... and having...fully compatible outdoor fluorescent lighting



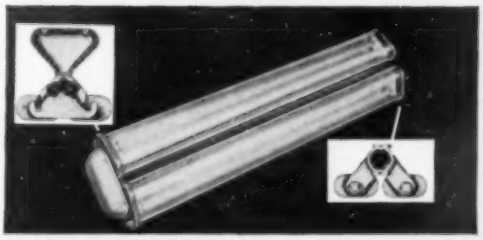
SINGLE LUXaire UNIT

LUXaire cut-out view shows P & K design and engineering features which result in high light output with excellent color retention, and without excess glare. LUXaire is strong, light-weight, and permanently sealed against dirt, water and insects. In 2-ft., 4-ft. and 6-ft. models.



DOUBLE LUXaire UNIT

Two single LUXaire units in one assembly for high intensity lighting with an unusually wide range of light patterns attainable through the P & K designed lateral swivel adjustment of each of the units. Adjusts both laterally and vertically. In 6-ft. models.



P&K LUXaire®

Municipal and commercial installations in greatly diversified geographic areas have proved P & K LUXaire entirely practical.

Produced in single or double units, LUXaire design and construction features provide greatly advanced characteristics in light placement, mechanical versatility, appearance, and maintenance-operation economies.

The P & K LUXaire is produced in a complete family of sizes: 2-ft., 4-ft. and 6-ft. models in single LUXaire units, and 6-ft. models in double LUXaire units, with companion standards if desired.

LUXaire also features a remotely housed ballast, eliminating excessive weight; the need for heavier supporting standards, and obsolescence of the entire luminaire in conversions to high intensity lamps now being developed.

TIME AND WEATHER TESTED LUXaire INSTALLATIONS

4-ft. Residential

6-ft. Commercial Facility

6-ft. Parking Area

WRITE FOR A COPY OF THE P & K LUXaire CATALOG...AND USE THE P & K ADVISORY SERVICES WITHOUT OBLIGATION.

S As filed in Sweet's Catalog.

Pfaff & Kendall 84 Foundry Street Newark 5, New Jersey

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Slimline *Lead-lag* ballasts
...for lighting economy

Know what it costs to send him up a ladder?

Fifty cents a round trip—maybe more. But half his effort may be unnecessary! It's this simple: If you are using series-type ballasts in your lighting fixtures and a lamp burns out, the other lamp burns dimly or goes out completely. The maintenance man has no way of knowing which lamp is defective unless he takes the time to test both. NOT so with Westinghouse slimline *lead-lag* ballasts—when one lamp burns out, the other lamp is not affected. Thus, valuable maintenance time is saved without the possibility of wasting good lamps or losing light. In addition, Westinghouse slimline *lead-lag* ballasts have a new UI core design to give you a cooler, quieter, more efficient operation.

Planning a new lighting system? Specify Westinghouse slimline *lead-lag* ballasts for real lamp replacement economy.

More information? See your Westinghouse representative or write Westinghouse Electric Corporation, Lighting Division, Edgewater Park, Cleveland, Ohio. J-04395

YOU CAN BE SURE...IF IT'S

Westinghouse

(*Continued from page 48A*)

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(*Continued on page 52A*)

"I'm glad we use CHAMPION Lamps around here. With the service we're getting out of 'em they're the best buy in Lamps."
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CHAMPION FLUORESCENT LAMPS
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A DIVISION OF CONSOLIDATED ELECTRIC LAMP CO.

design by mc Philben

A Recessed Weathertight Downlight

Good-looking, extra shallow, rugged . . . engineered for severe weather and corrosive conditions

Entrances, canopies, lobbies, vestibules, corridors, shower rooms . . . this extra shallow recessed downlight meets all your requirements . . . where appearance is important and non-corrosiveness vital.

FACE PLATE . . . of cast satin aluminum . . . is anodized for extra weather protection . . . features the new Sealume gasket to insure weather-tight operation within the lighting unit . . . simultaneously eliminates ceiling dust streaks and light leaks visible from without.

HOUSING . . . of 16 gauge galvanized . . . can either be used as a concrete pouring form . . . or mounted in recesses already provided by using wood forms. For plaster-type ceilings, use plaster frame. Attach hinged face plate and tighten screws so Sealume gasket is compressed tight against the ceiling.

IT'S AVAILABLE with round or square diffusers providing either symmetrical or asymmetrical light distribution from 60 Watts to 300 Watts . . . **extra shallow . . .** with corresponding depths from 2½" to 6¾". Protective guards, if desired. For full data on this series, write for the "43" line.

1353 Willoughby Avenue, Brooklyn 37, N. Y.

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(*Continued from page* 51A)

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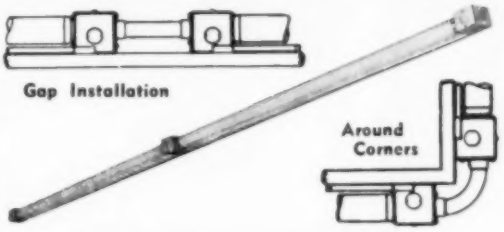

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In Those Hard-to-get-at Places

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If you can allow 2" x 2¼" space, you can have the advantages of standard relampable, trouble-free, economical slimline where formerly only luminous tubing could be used.

Available in 48", 72" and 96" single lamp lengths . . . Up to 384" with 4 lamps. One remote ballast box required every 32'. All ETL equipped.

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MILWAUKEE
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. . . describes Wiley's new Zephyrs. Their beautiful unadorned lines harmonize so well with *any* decor that you're unaware of the source of light. Their wafer-like thinness makes them ideally suited to installations where recessed fixtures cannot be used.

They may be arranged end to end, side by side to form squares, rectangles, borders. They may be mounted flush or suspended. You may have your choice of shielding: louvered (molded one piece polystyrene grid, metal egg-crate) or glass (Corning flat or curved lens).

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DEARBORN AND BRIDGE STS.
PIONEERS IN FLUORESCENT LIGHTING
BUFFALO 7, NEW YORK

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when you use Kliegl lighting fixtures

If you have a lighting problem that requires a deft touch to create some special effect or illuminate a prescribed area, Kliegl can be depended upon to furnish the right solution.

Whether the area is in a public building, commercial establishment, office, church, school, theatre or private home, Kliegl lighting fixtures are **so versatile** they can be used successfully. We manufacture the most complete line of Architectural Lighting Fixtures available. Fully catalogued with engineering data, sizes and specifications. Ask for catalog A-11D

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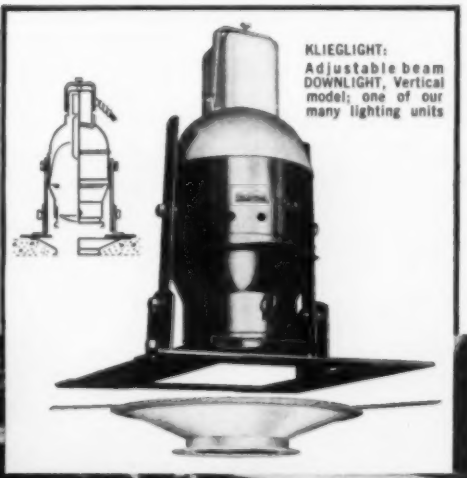

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Architectural Lighting Division

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Lighting
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Originators and Manufacturers of Klieglights

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Workmen at Light and Power Utilities Corp. are proud—proud that the finest materials, the keenest know-how, and the highest standards of quality and performance are part of every L & P fluorescent lighting fixture they make.

We, in turn, are proud of our L & P craftsmen. For they, after all, are your surest guarantee of the efficiency, dependability and economy you have come to expect from L & P fixtures.

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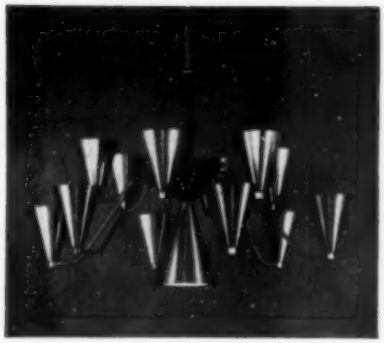

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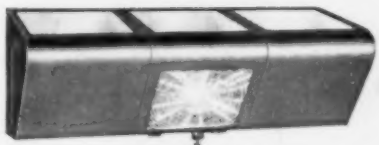

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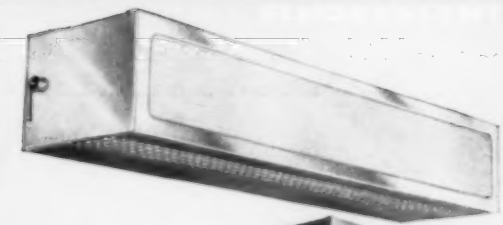

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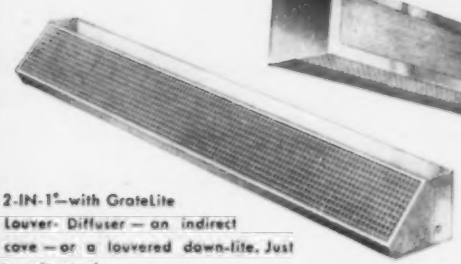

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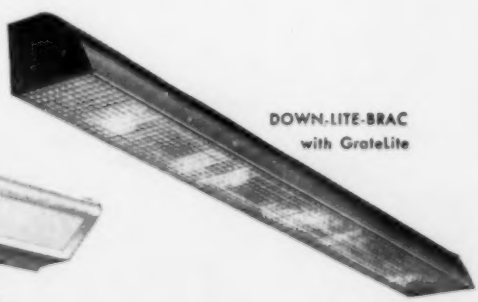

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